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ATOMIC PACKING MODELS OF SOME COMMON SILICATE STRUCTURES

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INTRODUCTION

*"In my opinion . . . the student, . . . will be well repaid if he makes models of the structure for himself . . . one gains an exceedingly intimate knowledge of the structure while building them No study of a diagram can teach as much Even when one has considerable experience of 'thinking in three dimensions' it is no easy matter to visualize a complex structure by studying a two-dimensional diagram."*¹

The importance of models that illustrate the atomic packing in crystals has already been noted.² They serve a different purpose than the "nuclear" crystal models. Atomic packing models are helpful in the study of gliding, coordination, exsolution, isomorphism, polymorphism, cleavage, the relation between crystal structure and habit, and other problems in which a knowledge of the atomic positions, relative sizes and packing is essential. The nuclear models are largely restricted to show the symmetry and point positions and convey no idea of the relative atomic radii.

The silicates are among the most difficult structures to visualize. The purpose of this paper is to present construction data for models of some of the more representative silicates.

¹ Bragg, W. L., *Atomic Structure of Minerals*, Ithaca, 1937, p. 47.

² Buerger, M. J., and Butler, R. D., A technique for the construction of models illustrating the arrangement and packing of atoms in crystals: *Am. Mineral.*, vol. 21, pp.150-172, 1936.

Buerger and Butler² have perfected a technique for the construction of atomic packing models. These are built on a scale of one inch = two Ångström units. The methods of calculation of the drilling coordinates are outlined in their paper and need not be described here. In the silicate models the silicon atoms are made of lead shot of such size that one nestles exactly in an oxygen tetrahedron. It was therefore unnecessary to calculate the silicon drilling coordinates or the silicon-oxygen bonds.

The models were prepared under the direction of Prof. M. J. Buerger, to whom we are indebted for many valuable suggestions. Mr. Ely Mencher prepared many of the photographs. The diagrams were made by the individual writers.

ZIRCON

(J. A. Shimer)

The following data for the crystal structure of zircon are given by Wyckoff and Hendricks.³

Space Group D_{4h}^{19}

Unit cell: $a = 6.58\text{Å}$
 $c = 5.93\text{Å}$

Zr is on Wyckoff's equipoint (b), (symmetry V_d) at $[[0, 0, 0]]$

Si is on Wyckoff's equipoint (a), (symmetry V_d) at $[[0, 0, \frac{1}{2}]]$

O is on Wyckoff's equipoint (h), (reflection planes) at $[[0, u, v]]$, where $u = 0.20$, or one-fifth the unit cell dimension a , and $v = 0.34$, or one-third c .

The Si atom, coordinates $[[0, 0, \frac{1}{2}]]$, has

Neighbors	Coordinates	Distance
4 O	$0, u, \frac{1}{2} - v$	1.62Å
2 Zr	$0, 0, \frac{1}{2}$	2.97Å
8 O	$\frac{1}{2}, u, v - \frac{1}{4}$	3.58Å

A Zr atom, coordinates $[[0, 0, 0]]$, has

Neighbors	Coordinates	Distance
4 O	$0, \frac{1}{2} - u, \frac{1}{4} - v$	2.05Å
4 O	$0, u, v$	2.41Å
2 Si	$0, 0, \frac{1}{2}$	2.97Å

We may consider the structure made up of strings parallel to the c -axis, each string being composed of alternate SiO_4 and Zr units. Each Zr atom joins the SiO_4 tetrahedra from the four neighboring strings. The O atoms in the silica tetrahedra were assumed to touch each other and the shortest distance between an O and a Zr atom was assumed to be the sum of their radii. Using these assumptions and the data given, the approximate atomic radii may be calculated as $\text{O} = 1.32\text{ Å}$, and $\text{Zr} = 0.73\text{ Å}$. Drilling coordinates and other data are given in Table 1.

In putting the model together, the SiO_4 tetrahedra were first assembled. Then bridges of two tetrahedra and a connecting Zr atom were formed. These bridges were built up to form the model. Top and side views are shown in Figs. 1 and 2, respectively.

³ *Zeits. Krist.*, vol. 66, pp. 73-102, 1927.

TABLE 1. DATA FOR THE CONSTRUCTION OF A PACKING MODEL OF ZIRCON

Ball designation	Ball diameter	Number of balls required for 2 unit cells	Drilling coordinates		Pin joins ball to
			ρ	ϕ	
Zr	$\frac{11}{16}$ "	22	75	0, 180	O
			105	90, 270	O
O	$1\frac{5}{16}$ "	72	35	0, 120, 240	O
			160	180	Zr
			139.5	0	O

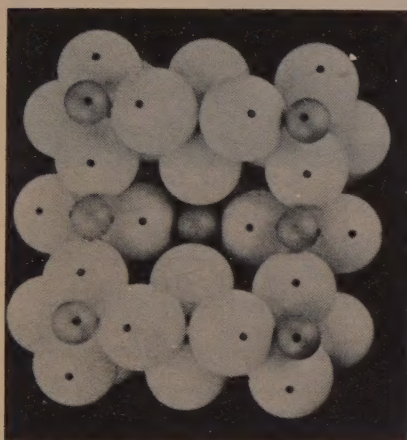


FIG. 1

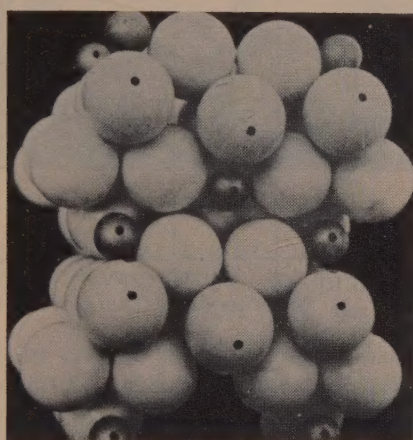


FIG. 2

FIG. 1. Top view of the zircon structure. Viewed parallel to c axis.

FIG. 2. Side view of the zircon structure. Viewed almost parallel to an a axis.

OLIVINE

(J. E. Dorris)

The most complete structural description of the orthosilicate, olivine, is that of W. L. Bragg and G. B. Brown.⁴ They determined the following data for Mg_2SiO_4 (forsterite):

Space Group: V_h^{16}

Unit Cell: $a = 4.75\text{\AA}$

$b = 10.2\text{\AA}$

$c = 5.99\text{\AA}$

The calculation of the drilling coordinates (given in Table 2) is relatively simple once the structural plan is grasped. Diagrams illustrating the symmetry, coordination and packing are given in the paper cited, in

⁴ *Zeits. Krist.*, vol. 63, pp. 538-556, 1926.

Strukturbericht,⁵ and in a summary of silicate structures by W. L. Bragg.⁶

In general, the structure of olivine may be likened to one showing hexagonal close packing, in which the SiO_4 tetrahedra have been slightly displaced or thrust apart by the Mg atoms. The radius ratio of Mg to O is too great to permit close packing.

TABLE 2. DATA FOR THE CONSTRUCTION OF A PACKING MODEL OF OLIVINE

Ball designation*	Ball diameter	Number of balls required for the model as illustrated in Fig. 4	Drilling coordinates		Pin joins ball to
			ρ	ϕ	
O (I)	$1\frac{5}{16}"$	18	35 145	0, 120, 240 0, 120, 240	2 O (III), O (II) 2 O (III), O (II)
O (II)	$1\frac{5}{16}"$	18	35 58.6 90 121.3 145	30 102, 318 0, 60 210 30	O (I) 2 Mg (I), 2 O (III) Mg (II) O (I)
O (III R) and O (III L)	$1\frac{5}{16}"$	36	35 58.6 90 145	30 102, 318 0, 60 30	O (I) Mg (I), Mg (II) O (II), O (III) O (I)
Mg (I)	$\frac{3}{4}"$	26	90	0, 79, 180 259	2 O (II), 2 O (III)
Mg (II)	$\frac{3}{4}"$	18	90 164	0, 79 210	2 O (III) O (II)

* The same notation is used here as was used by Bragg and Brown in their original paper cited in footnote 6.

There are two types of magnesium atoms designated by the symbols Mg (I) and Mg (II). The Mg (I)-types occur at centers of symmetry between reflection planes. There are three different types of oxygen atoms, each having different drilling coordinates and denoted by the symbols O(I), O(II) and O(III). The O(I)-atoms are at the apices of pyramids formed by the silica tetrahedra and lie on reflection planes. The O(II)-and O(III)-atoms form the base of the pyramid and lie in the b - c axial plane. The O(III)-atoms lie between the reflection planes. Thus for a given silica tetrahedron, there are two O(II)-atoms for every O(I)- and O(III)-type.

⁵ *Zeits. Krist.*, pp. 352-353, 1931.

⁶ *Zeits. Krist.*, vol. 74, p. 242, 1930.

As indicated by its classification, olivine consists of independent SiO_4 groups. Each group is linked to three Mg atoms which, in turn, link together the isolated SiO_4 groups.

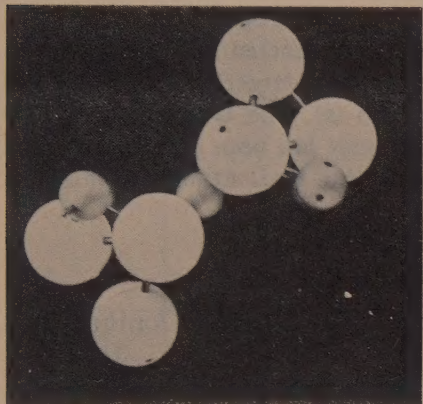


FIG. 3(a)

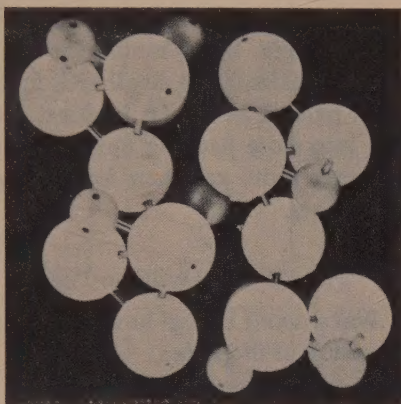


FIG. 3(b)

FIG. 3(a). Two SiO_4 tetrahedra of olivine arranged about Mg (I) with the a -axis oriented in a N-S direction. The Si atoms are missing.

FIG. 3(b). Same as Fig. 3(a) but with two more tetrahedra added.

The assembling of the model will be made easier if the reader bears the following in mind. The fundamental unit of construction, or "building block" is the SiO_4 tetrahedron with three Mg atoms attached. These units are built into a second unit which consists of six tetrahedra. The first step is the linking of the two tetrahedra by a Mg atom at a center

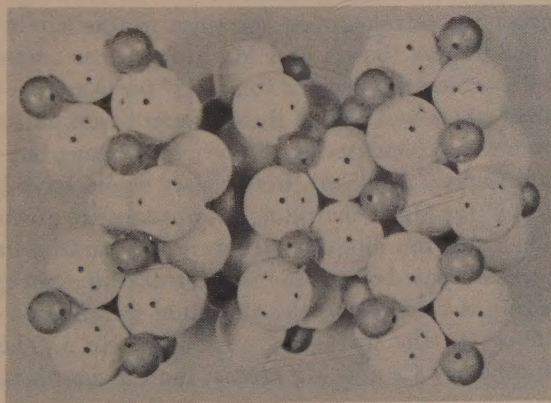


FIG. 4. The completed model of olivine viewed along a , with b oriented E-W and c is N-S.

of symmetry, Mg(II), as shown in Fig. 3(a). Two more tetrahedra are added as shown in Fig. 3(b). There are two vertical pairs of tetrahedra joined to one another by a single Mg atom at a center of symmetry. To complete the second unit, a third pair of tetrahedra is joined to either one of the first two pairs in a similar fashion. For a model of the size shown in Fig. 4, two more such units are constructed. It should be noted that the balls in the small SiO_4 unit and in the larger unit should be left open packed as shown in Figs. 3(a) and (b). The balls should not be put into close packing until the larger unit has been constructed. The separate units are then joined together by MgII atoms which lie on screw axes.

DIOPSIDE

(William Parrish and W. C. Güssow)

Warren and Bragg⁷ have determined the following data for the crystal structure of diopside:

Cell dimensions:	Space Group C_{2h}^6 [C 2/c]
$a = 9.71\text{\AA}$	Four molecules of $\text{CaMg}(\text{SiO}_3)_2$
$b = 8.89\text{\AA}$	per unit cell.
$c = 5.24\text{\AA}$	
$\beta = 74^\circ 10''$	
Coordination	Distance between atomic centers
Ca to 8 O	Ca—O, 2.35 \AA
Mg to 6 O	Mg—O, 2.10 \AA
Si to 4 O	O—O, 2.7–2.9 \AA

From these data we can calculate the approximate atomic radii as $\text{O} = 1.35\text{\AA}$, $\text{Ca} = 0.95\text{\AA}$, $\text{Mg} = 0.70\text{\AA}$. From the preliminary drawings it was apparent that unless a large number of trial drawings were made, the orientation of the tetrahedra in the silica chains would have to be changed in order to give the Ca and Mg atoms their correct sizes and coordination. We arbitrarily decided to use $1\frac{1}{4}''$ for O and let the Mg and Ca take the sizes which would give them proper coordination. Thus the silica chain remains as calculated by Warren and Bragg but the relative atomic radii are slightly distorted. Better sizes would have been $1\frac{3}{8}''$ for O, $1''$ for Ca and $\frac{3}{4}''$ for Mg. The drilling coordinates are given in Table 3.

The silica chains in the diopside structure are parallel to the c -axis. These chains are composed of regular SiO_4 tetrahedra. One oxygen atom of the tetrahedron is common to the adjoining tetrahedron so that the Si—O ratio reduces to the metasilicate ratio of 1 to 3. The chains are bound to each other by Ca and Mg atoms; the Ca coordinated to 8 and the Mg to 6 oxygen atoms.

⁷ Warren, B., and Bragg, W. L., *Zeits. Krist.*, vol. 69, p. 168, 1928.

TABLE 3. DATA FOR THE CONSTRUCTION OF A PACKING MODEL OF DIOPSIDE

Ball designation	Ball diameter	Number of balls required for model as illustrated in Fig. 7	Drilling coordinates		Pin joins ball to
			ρ	ϕ	
O _{1R} (+.84)	1 $\frac{1}{4}$ "	8	0	0	Ca
			41	103.5	
			58.5	265.5	
			105.5	304	
			113.5	240.5	
			131	103.5	
O _{1L} (-.84)	1 $\frac{1}{4}$ "	4	0	0	Ca
			49	103.5	
			66.5	240.5	Mg
			74.5	304	
			121.5	265.5	Ca
			139	103.5	
O _{2R} (+2.14)	1 $\frac{1}{4}$ "	8	0	0	Mg
			38	355	
			58.5	274.5	
			135.5	70.5	
O _{2L} (-2.14)	1 $\frac{1}{4}$ "	4	0	0	
			38	5	
			58.5	85.5	
			135.5	289.5	
O _{3R} (+.17)	1 $\frac{1}{4}$ "	8	0	0	Ca
			38	185	
			74.5	124	
			98	0, 180	
			113.5	60.5	
			133	236	
			157.5	352	
O _{3L} (-.17)	1 $\frac{1}{4}$ "	8	0	0	Ca
			38	175	
			74.5	236	
			98	0, 180	
			113.5	299.5	
			157.5	8	
Mg	7/8"	8*	0	0	
			89	0	
Ca _R (+1.52)	1 $\frac{1}{4}$ "	6*	0	0	O 1R O 2R O 3R O 3L
			41	103.5, 283.5	
			76	35, 215	
			123	133.5, 313.5	
			133	56, 236	
Ca _L (-1.52)	1 $\frac{1}{4}$ "	6*	0	0	O 3R O 3L O 2L O 1L
			47	56, 236	
			57	133.5, 313.5	
			104	35, 215	
			139	103.5, 283.5	

* If more Ca and Mg balls are added, as has been done with the model in Fig. 7, the symmetry is more readily seen.

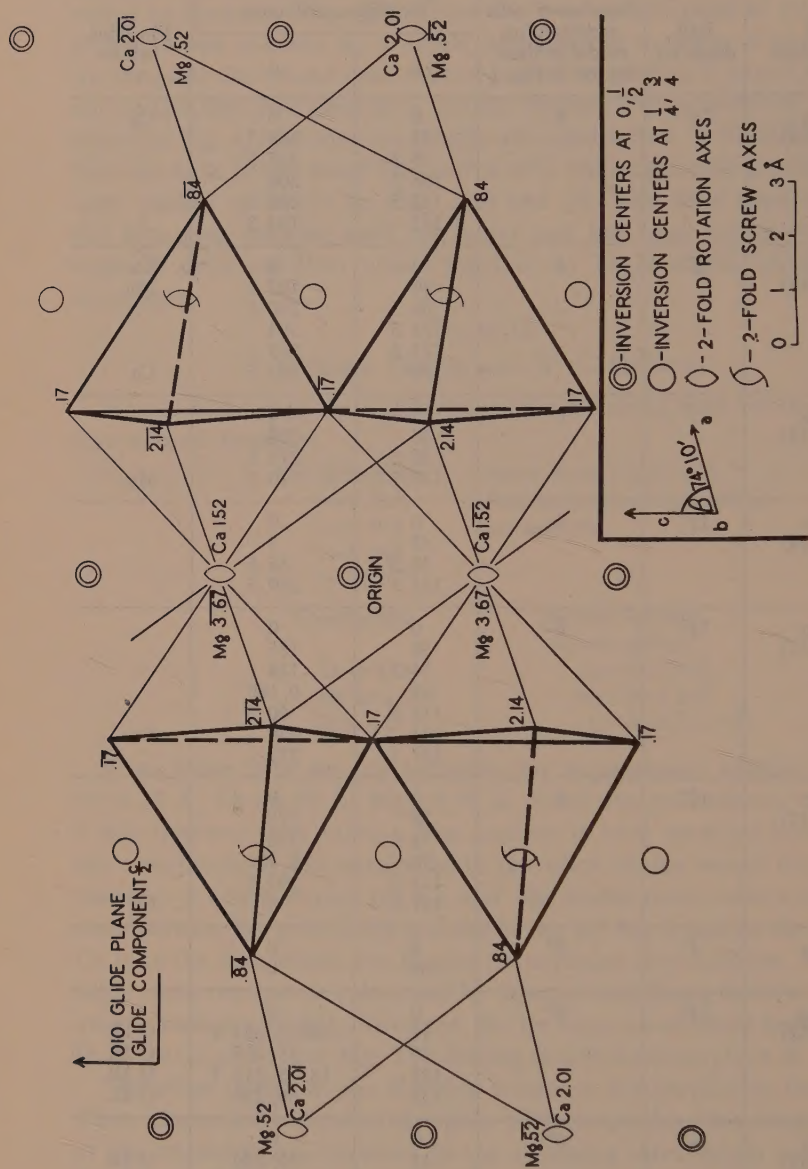


FIG. 5. Projection of the diopside structure on plane (010). This diagram shows the pinning directions and the symmetry elements. All the ϕ -angles can be read directly. Numbers refer to the distance above or below the plane of the paper. To facilitate interpretation, Figs. 6(a) and (b) and Table 3 are figured in the same manner. Modified from Warren and Bragg.

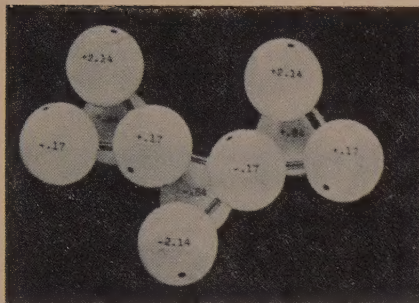


FIG. 6(a). The diopside metasilicate chain left open and the Si atoms omitted. Shows the pinning of the various O atoms.

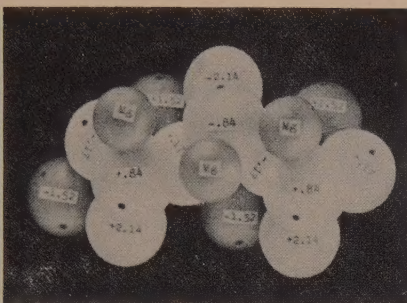


FIG. 6(b). Bottom view of Fig. 6(a), with Si, Mg and Ca atoms added. This shows the packing of the important unit of the structure.

The construction of the model is made easier if the initial holes of the oxygen atoms are marked in such a manner that they can be easily recognized when putting the model together. It is advisable to make the silica chains first and leave them open as shown in Fig. 6(a). The whole silica chain is then closed and enough Ca and Mg atoms are added to tie two silica chains together. Figures 5-7 illustrate various aspects of the diopside structure.

The writers are indebted to Mr. O. N. Rove for aid in making the calculations.

MUSCOVITE (Clifford Frondel)

Muscovite can be visualized as built up of paired "mica sheets" (extended planar Si_4O_{10} groups) placed so that the bases of the SiO_4 tetrahedra are symmetrically opposed. A 12-coordinated K atom is situated between the opposing basal hexagonal oxygen rings of these sheets, with 8-coordinated OH groups situated at the center of the hexagons formed by the apical oxygens of the silica tetrahedra in each oppositely facing sheet.

These blocks of paired sheets, with their K and OH atoms, are stacked in the crystal so that each block is displaced over the next underlying block for a distance of $\frac{1}{3}a$ at an angle of 30° with b , and are bound to the adjacent blocks by a layer of 6-coordinated Al atoms (Mg or Fe in phlogopite or biotite). Diagrams illustrating the stacking of the blocks and the positions of the various atoms can be found in the original description by Jackson and West⁸ and in a recent account by Bragg.⁹

⁸ Jackson, W. W., and West, J., *Zeits. Krist.*, vol. **76**, p. 211, 1930; vol. **85**, p. 160, 1933.

⁹ Bragg, W. L., *Atomic Structure of Minerals*, Ithaca, pp. 205-210, 1937.

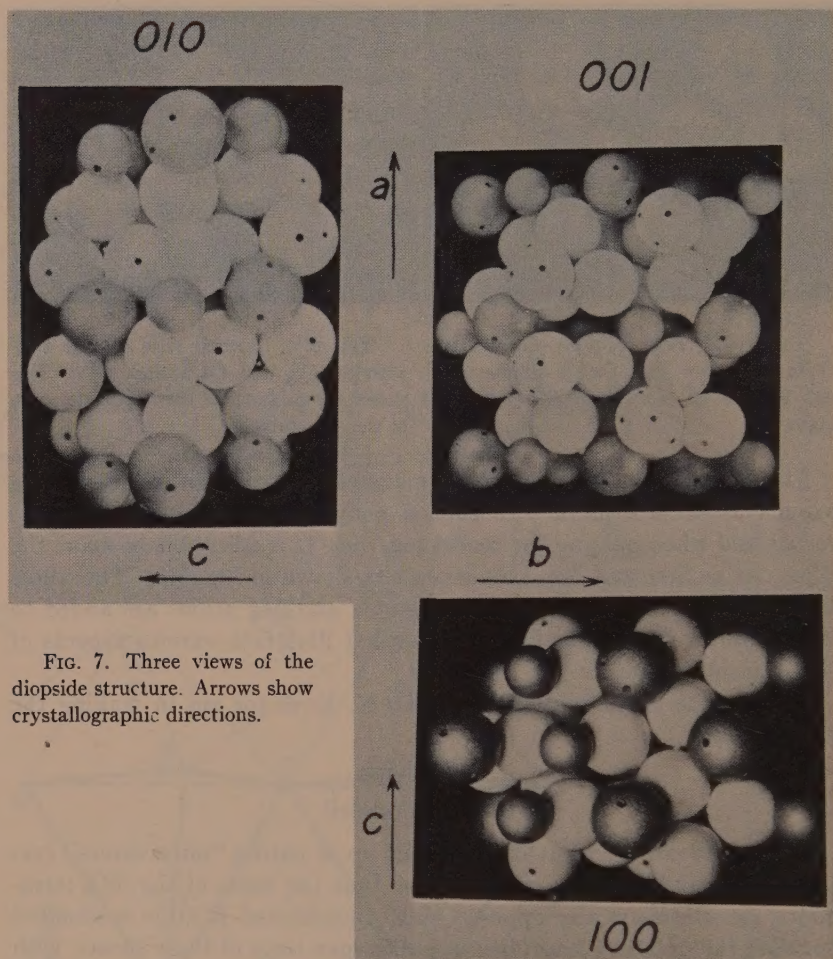


FIG. 7. Three views of the diopside structure. Arrows show crystallographic directions.

It should be noted that the blocks by themselves possess hexagonal symmetry, but that the method of stacking of the blocks degrades the symmetry to monoclinic. The shift between each block gives $\beta = 95^\circ$.

The cleavage takes place through the K planes. A system of "open" channels also runs through the structure in the (001) K planes. These openings probably are the loci of deposition of the exsolution growths of hematite and rutile frequently found in muscovite and phlogopite, respectively.

Ball sizes were so chosen as to maintain as nearly as possible the relative values of the radii proper to the various kinds of atoms in the crys-

tal. The OH groups, which are strongly polarized in the crystal, are represented by single balls in the model. The most satisfactory ball size for OH was found by calculation to be $1\frac{5}{16}$ ". This size necessitates increasing the Al atoms slightly above their proper diameter, but maintains the interplanar spacing rather closely. The drilling coordinates calculated for the adjusted structure, are given in Table 4. The data comprise one unit cell plus enough exterior atoms to give the model a hexagonal aspect.

TABLE 4. DATA FOR THE CONSTRUCTION OF A PACKING MODEL OF MUSCOVITE

Ball designation	Ball diameter	Number of balls required for model as illustrated in Fig. 10	Drilling coordinates		Pin joins ball to
			ρ	ϕ	
K	$1\frac{3}{4}$ "	14	59 121	0, 120, 240 0, 120, 240	basal O basal O
OH	$1\frac{5}{16}$ "	28	90	0, 120, 240	apical O
Al	$\frac{3}{4}$ "	51	(one through hole)		apical O
basal O	$1\frac{5}{16}$ "	48	90 145	0, 60, 180, 240 30, 210	basal O apical O
basal O	$1\frac{5}{16}$ "	126	90 145 59	0, 60, 180, 240 30, 210 120, 300	basal O apical O K
apical O	$1\frac{5}{16}$ "	48	35 90 122	0, 120, 240 60, 180, 300 30	basal O OH Al
apical O	$1\frac{5}{16}$ "	48	35 122	0, 120, 240 330	basal O Al

The model is best assembled by making each single mica sheet with its OH atoms separately (Figs. 8, 9), then pinning these sheets together with K atoms to form the blocks already mentioned, and finally stacking the completed blocks to form the entire cell (Fig. 10). The blocks are pinned together by means of the Al atoms. The Al balls should be drilled with a single through hole, the other bonds being eliminated, and be attached by a single $1\frac{1}{2}$ " pin. The pins should all face in the same direction (Fig. 9), and the overlying block can then be slid directly on the lower block.

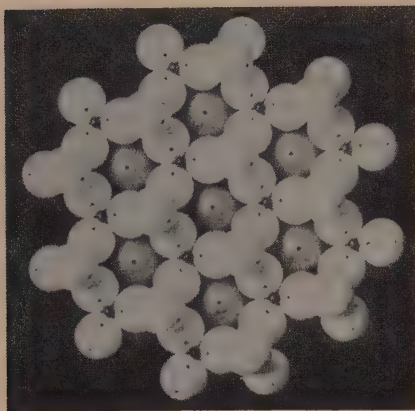


FIG. 8. Planar Si_4O_{10} sheet. Alternate apical oxygens are left off, exposing the Si atoms in the interior of the SiO_4 tetrahedra. In constructing the sheet, the alternate missing apical oxygens are attached directly to the OH balls and this network is pinned to the mica sheet as a unit. Alternate oxygen bonds on the OH balls are eliminated for ease in construction.

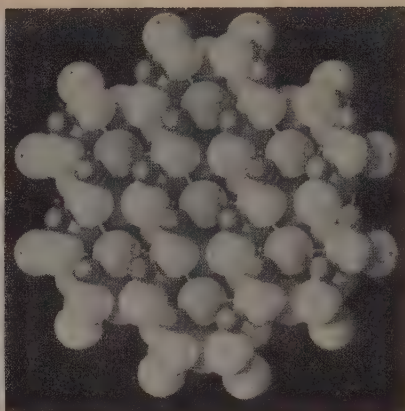


FIG. 9. Completed "mica sheet." The alternate apical oxygens and the OH groups, missing in Fig. 8, are shown in place together with the Al atoms.

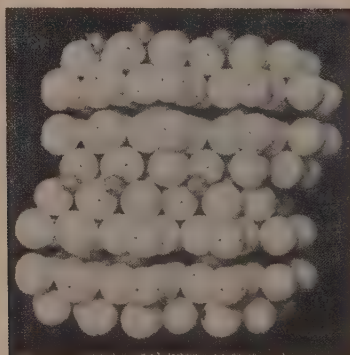


FIG. 10. Completed model. The model is viewed almost along b , and the monoclinic nature of the cell can be seen. The plane of cleavage through the K atoms, and the channels in this plane are apparent.

SANIDINE

(C. S. Lord and V. M. Lopez)

The structure of sanidine has been described by Taylor.¹⁰ Certain

¹⁰ Taylor, W. H., The structure of sanidine and other feldspars, *Zeits. Krist.*, vol. **85**, p. 425, 1933.

permissible generalizations and simplifications have been adopted in this note in order to avoid needless complexity in the calculation and construction of the model.

The space group is given as C_{2h}^3 . Alternative unit cells with symmetry elements (as given by Taylor) and the correlation of the model with his cells are shown in Fig. 11. Essential symmetry elements which cannot be illustrated in Fig. 11 are given in Taylor's paper. All further constructional data, with appropriate generalizations as justified below, are derived directly from these drawings.

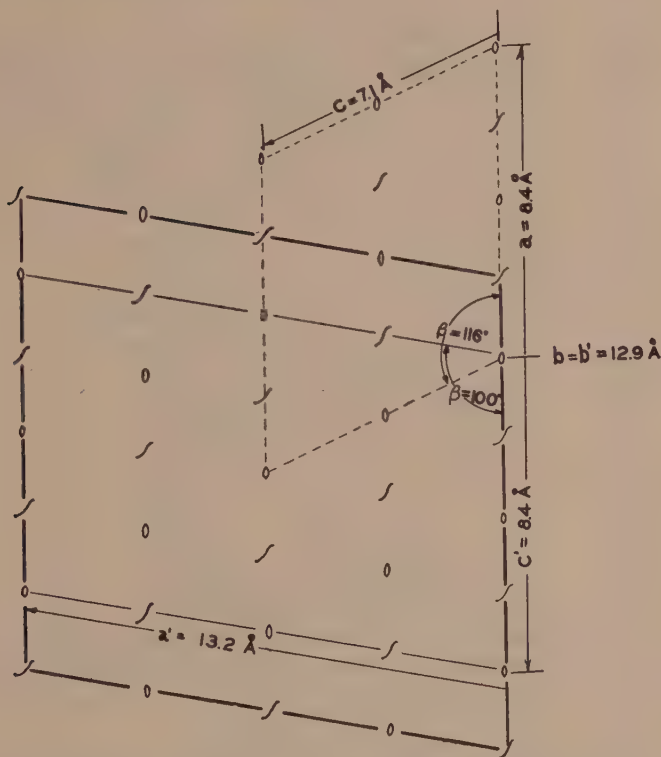


FIG. 11. Two alternative unit cells as given by Taylor. The heavy outline shows the arbitrary limit of the model.

It is difficult to visualize the structure from Taylor's drawings because all atoms are shown as points. Since the fundamental unit of the structure is a tetrahedron of oxygen atoms enclosing either a Si or Al atom, his point drawings can at once be simplified by substituting a solid

tetrahedron for each group of oxygen atoms, as in Fig. 12(a). Si and Al atoms were omitted from these drawings because they occupied a fixed position within these solid tetrahedra.

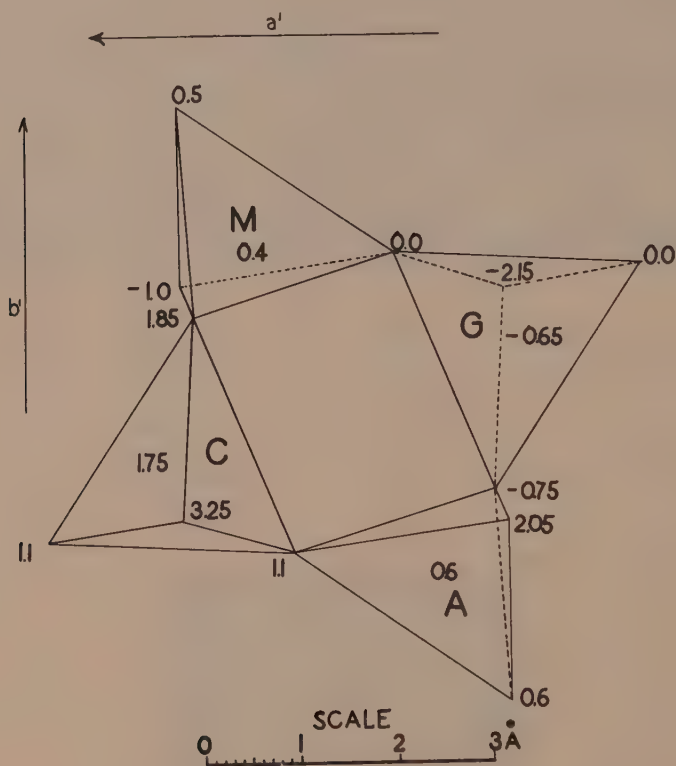


FIG. 12(a). The "basic ring" of tetrahedra as given by Taylor. Simplified only by the substitution of solid tetrahedra for his "point drawing." Viewed in plane of $a'b'$ of Fig. 11.

Taylor has pointed out that the fundamental tetrahedra may be conveniently grouped into "basic rings" of four tetrahedra each and the completed structural model may be built up of a series of these basic rings suitably oriented and linked.

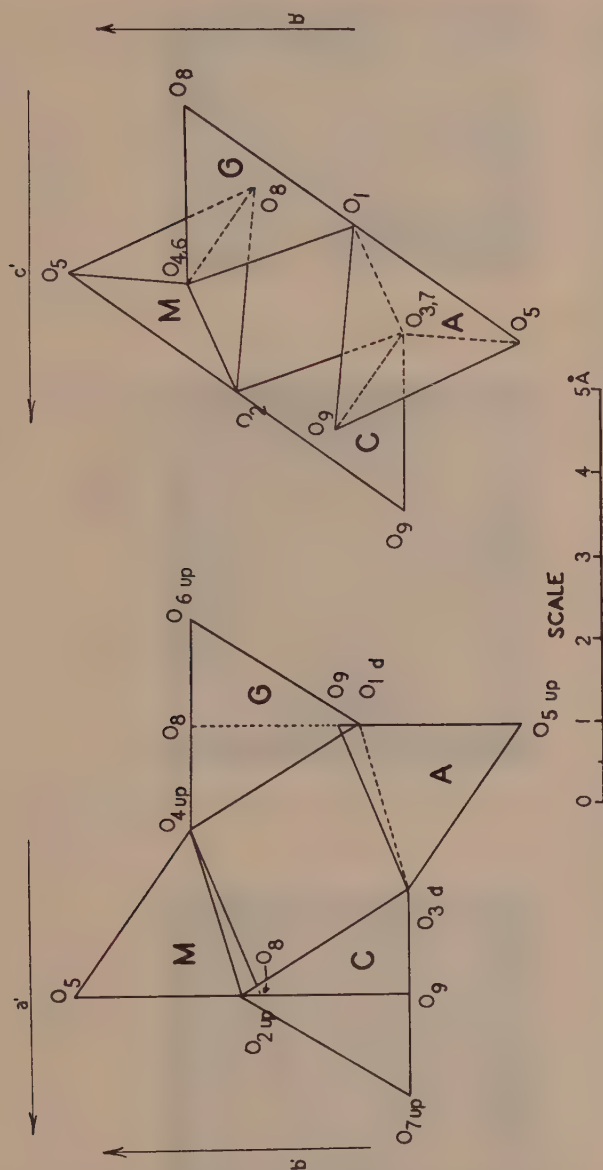


FIG. 12(b). Oriented and regularized "basic ring" of sanidine as used in the model. Same view as Fig. 12(a). This drawing is used to calculate the drilling coordinates of O_1 , O_2 , O_3 , and O_4 .

The basic ring was first simplified and regularized. This brought it to the form shown by the group *MCAG*, Figs. 12(b) and 13. This ring was then expanded by symmetry operations to form a sheet of four such



FIG. 13. Completed basic tetrahedron ring corresponding to the tetrahedron *MGHC* of Fig. 12(b), in plane of axes $a'b'$. K atoms are bonded to O_6 .

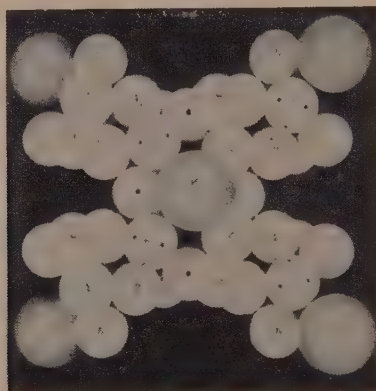


FIG. 14. "Sheet" comprising four basic tetrahedra rings with attendant K atoms. Numbers correspond to those used throughout the sanidine description. Viewed normal to the $a'b'$ axes.

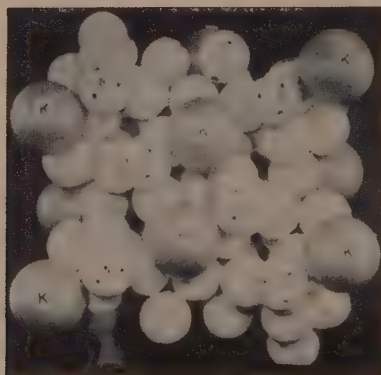


FIG. 15. Completed sanidine model oriented as Fig. 11.
Viewed parallel to the b' (or b) axis.

rings. K atoms were added and the completed sheet is shown in Fig. 14. Such a sheet lies in the plane $a' b'$ (Fig. 11). Three similar sheets, suitably bonded, complete the model of $1\frac{1}{2}$ unit cells as shown in Fig. 15.

In calculating the drilling coordinates, the tetrahedral groups were first regularized. Taylor's calculations show that the structure is made up of tetrahedra in which the Si-O and the O-O distances vary between 1.55 to 1.75 Å and 2.55 to 2.95 Å, respectively. It was not practical to construct a model of such complexity and the following simplifications were adjusted to the available ball sizes:

- (1) regular tetrahedra were used
- (2) O-O distances were taken as 2.50 Å.

The substitution of these regular tetrahedra at once necessitated a slight modification of the structure as given by Taylor. The "basic ring" was modified from the given form, as shown by the same group in Fig. 12(b). From this figure the drilling coordinates were calculated for the oxygen atoms designated O_1, O_2, O_3, O_4 .

In Fig. 16, the selected ring (*MCAG*) is shown oriented with respect to the symmetry elements so as to preserve the required symmetry and to properly pack about the K atoms. From this figure the drilling coordinates of O_5, O_6, O_7, O_8 and O_9 were determined. Atoms O_5, O_6 and O_7 link the selected ring to three other rings and serve to complete one sheet of the model (Fig. 16). Atoms O_8 and O_9 link this sheet to other sheets above and below.

With Taylor's geometry of the silicate linking, our arbitrary oxygen radius would have required a K atom radius of $2.85 - 1.25 = 1.60$ Å. However, our idealized model requires the K atom to be 1.72 Å, and this is the size we used. All the K atoms lie on reflection planes.

Drilling coordinates and other data are given in Table 5. The initial hole drilled for all oxygen atoms is not used as a bonding hole; this simplifies calculation of coordinates and aids in orienting the ball. In all cases these initial holes lie parallel to the "*C*" (or "*a*") axis and hence point either "up" or "down" in the cell as shown in Fig. 11. The designations "up" or "down" in the working drawings (Figs. 12 and 16) refer to the orientation of this initial hole on the C' axis and serve to orient the corresponding oxygen atom while constructing the model. K atoms were bonded by one pin only (to the O_5 atoms), hence the complete environment of the K atoms is lacking toward the border of the model. All oxygen atoms are shared by two tetrahedra.

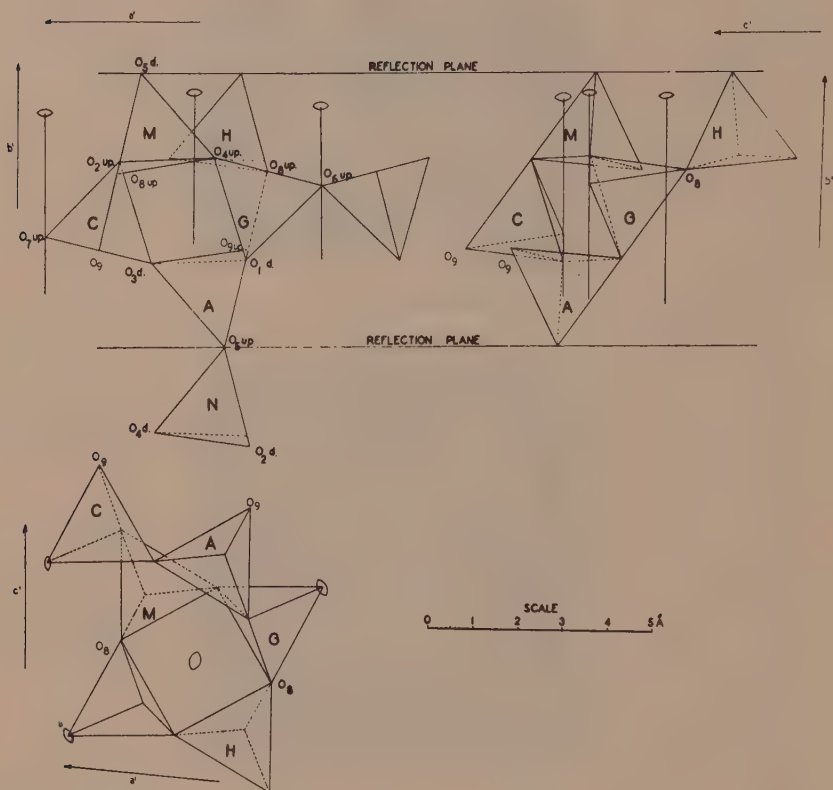


FIG. 16. Basic ring of tetrahedra expanded by symmetry operations and used to calculate the drilling coordinates of O_6 and O_8 . O_7 and O_9 are reflections of O_6 and O_8 , respectively. Initial holes marked "up" and "down" as in Fig. 13.

TABLE 5. DATA FOR THE CONSTRUCTION OF A PACKING MODEL OF SANIDINE

Ball designation*	Ball diameter	Number of balls required for $1\frac{1}{2}$ unit cells	Drilling coordinates		Pin joins ball to
			ρ	ϕ	
O ₁	$1\frac{1}{4}"$	14	0	0	
			54.5	0	
			107	32, 328.5	
			121.5	254	
			125.5	180	
			174	0	
O ₂	$1\frac{1}{4}"$	14	0	0	
			54.5	0	
			107	31.5, 328.5	
			121.5	106	
			125.5	180	
			174	0	
O ₃	$1\frac{1}{4}"$	14	0	0	
			58.5	164	
			90	0	
			93.5	215	
			107.5	58.5	
			118.5	157.5	
O ₄	$1\frac{1}{4}"$	14	0	0	
			58.5	196	
			90	0	
			93.5	145	
			107.5	301.5	
			118.5	202.5	
O ₅	$1\frac{1}{4}"$	20	0	0	K
			58	0	
			62.5	75.5, 284.5	
			93.5	130.5, 229.5	
			125.5	75.5, 284.5	
O ₆	$1\frac{1}{4}"$	4	0	0	
			30	14	
			73.5	315.5	
			90	14, 165.5	
			106.5	224	
			150	165.5	

* Subscripts in this column correspond to numbers on oxygen atoms in photos and to subscripts on same atoms in Figs. 12 and 16.

TABLE 5 (Continued)

Ball designation*	Ball diameter	Number of balls required for $1\frac{1}{2}$ unit cells	Drilling coordinates		Pin joins ball to
			ρ	ϕ	
O ₇	1 $\frac{1}{4}$ "	4	0	0	
			30	346	
			73.5	44.5	
			90	194.5, 346	
			106.5	136	
			150	194.5	
O ₈	1 $\frac{1}{4}$ "	18	0	0	
			30	0, 180	
			35	270	
			114.5	119.5	
			117.5	186.5	
			173.5	119.5	
O ₉	1 $\frac{1}{4}$ "	18	0	0	
			30	0, 180	
			55	90	
			114.5	240.5	
			117.5	173.5	
			173.5	240.5	
K	1 $\frac{1}{4}$ "	18	0	0	O ₅
			122	0	

ANTOFAGASTITE AND BANDYLITE, TWO NEW COPPER MINERALS FROM CHILE

CHARLES PALACHE, *Harvard University*, AND W. F. FOSHAG,*
U. S. National Museum.

ABSTRACT

Antofagastite $2[\text{CuCl}_2 \cdot 2\text{H}_2\text{O}]$. Orthorhombic dipyramidal ($2mm$). Space group ($Pbmn$). $a_0=7.38\text{\AA}$, $b_0=8.04\text{\AA}$, $c_0=3.72\text{\AA}$; $a_0:b_0:c_0=.918:1:462$ (artificial). Crystals rare. Curved and vermiform shapes. Cleavage $m(110)$ perfect, $c(001)$ good. Brittle. Conchoidal fracture. H $2\frac{1}{2}$. G 2.4 (natural crystals). Vitreous luster. Bluish green. Bx positive. $2V\ 75^\circ$. $r < v$. $X=b[010]=\text{bright green}=1.646$, $Y=c[001]=\text{olive green}=1.685$, $Z=a[100]=\text{pale blue}=1.745$. Occurs in Calama, Antofagasta, Chile, as a crust, with bandylite and atacamite. Named after the province.

Bandylite. $\text{Cu}_2\text{B}_2\text{O}_4 \cdot \text{CuCl}_2 \cdot 4\text{H}_2\text{O}$. Tetragonal holohedral ($4/m\ 2/m\ 2/m$). Space group $P\ 4/nmm$. $c=.907$. $a_0=6\ 13\text{\AA}$, $c_0=5.54\text{\AA}$. Thick tabular crystals. Cleavage $c(001)$ perfect. Flexible. H $2\frac{1}{2}$. G 2.810. Deep blue. Uniaxial negative; $\omega=1.692=\text{deep cendre blue}$, $\epsilon=1.640=\text{pale greenish yellow}$. Decomposed by water, CuCl_2 going into solution with green copper borate as a residue. Occurs in Calama, Chile, with antofagastite and atacamite as a crust on rock joints. Named after Mark C. Bandy, who collected the original material.

During the summer of 1935 Mr. Mark C. Bandy went to northern Chile to collect minerals in the joint interest of the U. S. National Museum and the Harvard Mineralogical Museum. Mr. Bandy's long service on the geological staff of the Chile Exploration Company at Chuquicamata had made him well acquainted with the local conditions, and the chief result of his work was a large suite of gossan minerals, largely sulphates, from three localities. The study of this suite of minerals has been carried on at Washington and Harvard, and the general results will be published soon by Mr. Bandy. This paper is confined to the description of two new copper minerals discovered among them.

These minerals occur together with atacamite near the surface at Mina Quetena, west of Calama, Chile. They are in a leached zone above massive iron sulphates. Crystals of both species are implanted on the surface of heavily iron-stained rock and quartz. The first mineral is known in artificial crystals but has not before been reported in a natural occurrence; the second appears to be quite new.

ANTOFAGASTITE

The first mineral to be described is a simple hydrous copper chloride, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, similar to the well known artificial compound. We propose the name *antofagastite*, from the Province of Antofagasta in which

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Calama is situated. It forms lichen-like splotches on the rock. The center of these splotches is occupied by small deeply grooved spires up to 5 mm. long, often bent or entirely recurved, much in the manner of some gypsum, chalcantite or similar soluble salts. About these columnar masses are areas of lighter colored efflorescence; other areas are little more than stain.

Chemical properties. Antofagastite is a hydrous chloride of copper, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$. This is the common laboratory hydrate but has never before been reported in nature. A small but carefully picked sample was available which, except for a slight admixture of gangue, was pure and homogeneous. The analysis of this material yielded the results given in Table 1.

TABLE 1. ANALYSIS OF ANTOFAGASTITE FROM MINA QUETENA, CALAMA, CHILE

	I	II
Insol.	0.95	
Cu	36.89	37.22
Fe_2O_3	0.20	
CaO	0.15	
MgO	0.04	
Cl	40.68	41.52
H_2O	20.81	21.26

I Analysis of antofagastite from Mina Quetena, Calama, Prov. of Antofagasta, Chile.
William F. Foshag, *analyst*.

II Theoretical composition for $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$.

Pyrognostics: Antofagastite is easily and completely soluble in water to a pale blue solution and in ammonium hydroxide to an intense blue solution. Before the blowpipe it fuses easily, coloring the flame green, blue near the assay; in a closed tube it yields water and fuses easily, recrystallizing to a yellow or light brown anhydrous chloride.

Crystallography. A few measurable crystals were found which gave the angles contained in Table 2. The elements calculated from these angles are very close to those previously determined on artificial crystals of this salt.¹

Antofagastite is orthorhombic dipyramidal.

$$a:b:c = 0.9177:1:0.4631.$$

$$p_0:q_0:r_0 = 0.5046:0.4631:1.$$

The structure lattice has been determined recently by Harker.² The

¹ Marignac, *Mem. Soc. Phys. Geneve*, vol. 14, p. 219, 1855; and Groth, *Chem. Cryst.*, vol. 1, p. 238, 1906. Artificial crystals: $a:b:c = 0.9174:1:0.4643$.

² Harker, *Zeits. Kryst.*, vol. 93, p. 136, 1936.

TABLE 2. ANTOFAGASTITE. MEASURED AND CALCULATED ANGLES

Forms	Calculated		Measured		No. of faces
	ϕ	ρ	ϕ	ρ	
<i>c</i> 001	—	0°00'	—	0°00'	2
<i>b</i> 010	0°00'	90 00	0°00'	90 00	11
<i>a</i> 100*	90 00	90 00	—	—	—
<i>m</i> 110	47 27½	90 00	47 28	90 00	9
<i>l</i> 520	69 50½	90 00	69 49	90 00	8
<i>q</i> 103*	90 00	9 33	—	—	—
<i>r</i> 101*	90 00	26 46½	—	—	—
<i>s</i> 301	90 00	56 33	90 00	56 38	3
<i>p</i> 111	47 27½	34 24½	47 20	34 12	1

* Forms found only on artificial crystals, together with *c*, *b*, *m* (see footnote 1).

unit cell has dimensions $a_0=7.38$, $b_0=8.04$, $c_0=3.72$; $a:b:c=0.918:1:-0.462$. It contains $\text{Cu}_2\text{Cl}_4 \cdot 4\text{H}_2\text{O}$. Space group ($P \bar{b} m n$).

Physical properties. Antofagastite is brittle with a conchoidal fracture and a perfect cleavage parallel to $m(110)$, good cleavage parallel to $c(001)$. The specific gravity is 2.4, determined on natural crystals. Hardness 2.5. Luster vitreous. Color bluish-green to greenish blue with at times a yellowish tinge.

	$n(\text{Na})$	Positive
X=[010] bright green	$\omega=1.646$	$2V=75^\circ$
Y=[001] olive green	$\beta=1.685$	$r < v$
Z=[100] pale blue	$\gamma=1.745$	

BANDYLITE

For the second species we propose the name *bandylite*, in honor of Mark C. Bandy, mining engineer, who collected this material and who has made a study of the sulphates and related minerals of the locality from which these two new species come.

Bandylite is tetragonal and occurs always in crystals and crystal aggregates. The crystals are sometimes attached to the rock as symmetrical pseudocubic or tabular individuals. More commonly a single distorted crystal, or cluster of several subparallel individuals spreads out in an irregular or circular button-like or lichen-like group. The crystals in these groups are much flattened parallel to the base or to the face of a pyramid. The groups are sometimes isolated, or sometimes united to cover considerable surfaces. They rest either on joint faces of altered volcanic rock or the walls of narrow cracks in vein quartz. Occasionally crystals of bandylite are implanted on iron-stained quartz crystals in vugs of the veins.

Composition. In order to obtain a suitable sample for analysis the material had to be carefully picked by hand under the binocular microscope. In this way a satisfactory sample was finally obtained, containing only a small per cent of admixed gangue but contaminated by a few per cent of antofagastite and atacamite. Analysis of this material yielded the results given in Table 3.

TABLE 3. ANALYSIS OF BANDYLITE, CALAMA, CHILE

	I	II	III
Insol.	1.84		
Cu	34.94	.5498	35.74
CaO	0.05		
MgO	0.05		
Na ₂ O	0.40		
K ₂ O	None		
Fe ₂ O ₃	0.35		
Cl	19.47	.5490	19.94
B ₂ O ₄	23.35	.2715	24.08
SO ₃	0.05		
H ₂ O	19.60	1.0888	20.24
Sum	100.10		

I Bandykite, Mina Quetena, near Calama, Chile. William F. Foshag, *analyst*.

II Molecular ratios from Col. I.

III Theoretical composition for $\text{CuB}_2\text{O}_4 \cdot \text{CuCl}_2 \cdot 4\text{H}_2\text{O}$.

The chemical analysis corresponds closely to the composition $\text{CuB}_2\text{O}_4 \cdot \text{CuCl}_2 \cdot 4\text{H}_2\text{O}$. The higher ratios of the Cu and Cl, above those of B_2O_4 are probably to be ascribed to the admixed antofagastite $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ and to atacamite.

Pyrognostics. Before the blowpipe bandylite colors the flame green, pale blue near the mineral fragment. In a closed tube it yields water and a yellow crystalline sublimate; in an open tube it yields water and a yellow sublimate that oxidizes black. The mineral is decomposable by water, copper chloride going into solution, verdigris-green copper borate remaining as an insoluble residue. Easily and quickly soluble in ammonium hydroxide to an intense blue solution; more slowly soluble in hydrochloric and nitric acids.

Crystallography. Bandykite is tetragonal, holohedral. Four crystals, including one doubly terminated individual, were measured; they gave excellent reflections and very consistent angles. The readings on nine faces of the form taken as (201) and thirteen faces of the form (111) on the four crystals were employed in calculating the axial ratio.

Forms	No. of faces	Mean		Range	
		ϕ	ρ	ϕ	ρ
<i>g</i> (201)	9	0°00'	61°05'	±0°05'	60°53'–61°11'
<i>p</i> (111)	13	45 00	52 06	±0 05	51 58–52 15

From (201): $c = \frac{1}{2} \tan \rho = 0.9051$

(111): $c = \sin \phi \tan \rho = 0.9083$

Weighted mean: $c = 0.9070$

The cell dimensions of the simple tetragonal lattice, determined by Dr. Berman, are a_0 6.13 Å, c_0 5.54 Å, with $a_0:c_0 = 1:0.904$, a ratio in good agreement with the morphological ratio $a:c = 1:0.9070$. Since the morphology indicates the holohedral crystal class $4/m\ 2/m\ 2/m$ the space group is $P\ 4/n\ m\ m$, fixed by the following observed reflections: hkl all orders present, $hk0$ only with $h+k$ even, and $0kl$ all orders present.

The molecular weight of the unit cell, $M = 354$, agrees excellently with that of the empirical formula, $M = 356$.

The forms observed and the angles, measured and calculated are contained in Table 4.

TABLE 4. BANDYLITE. MEASURED AND CALCULATED ANGLES

Forms	Calculated		$a:c=1:0.9070$ $\rho_0=0.9070$				No. of faces	Quality
			Measured		Range			
	ϕ	ρ	ϕ	ρ	ϕ	ρ		
<i>c</i> 001	0°00'	0°00'	0°00'	0°00'	—	—	5	very good
<i>a</i> 010	0 00	90 00	0 00	90 00	—	—	2	very poor
<i>m</i> 110	45 00	90 00	45 00	90 00	$\pm 3'$	—	3	very poor
<i>d</i> 012	0 00	24 23½	0 00	24 31	$\pm 3'$	24°25'–24°55'	7	good
<i>e</i> 023	0 00	31 09½	0 00	31 13	—	—	1	poor
<i>f</i> 011	0 00	42 12½	0 00	42 17½	$\pm 5'$	42 10–42 26	6	good
<i>g</i> 021	0 00	61 08	0 00	61 05	$\pm 5'$	60 53–61 11	9	very good
<i>o</i> 112	45 00	32 40½	45 00	32 44½	$\pm 2'$	32 43–32 46	2	good
<i>p</i> 111	45 00	52 03½	45 00	52 06	$\pm 5'$	51 58–52 15	13	very good
<i>q</i> 221	45 00	68 42	45 00	68 33	$\pm 5'$	68 16–69 00	5	poor

As shown in Figs. 1 and 2, the dominant forms are $c(001)$, $p(111)$, $g(201)$, and $m(110)$. Tabular crystals are the rule and these may be fully symmetrical with a square basal plane or with a rectangular outline. However, irregular development is much more common, and pyramidal faces may be largely developed. The base can generally be recognized by its superior lustre, occasionally pearly where cleavage is developed, and by frequently developed, low quadrangular terraces.

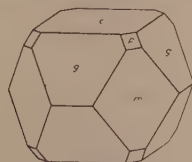


FIG. 1



FIG. 2

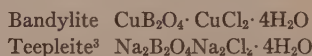
Physical and optical properties. The cleavage is basal (001), perfect and easy. Hardness $2\frac{1}{2}$. Specific gravity 2.810 by pycnometer (Berman). Very flexible and easily deformed.

The color is deep blue with greenish lights, cendre to Italian blue (Ridgway), becoming greener from atacamite inclusions. It is pale blue when bruised or powdered. The mineral is optically uniaxial and negative. Undistorted crystals, carefully removed from the matrix are either completely uniaxial or show a slight opening of the cross. Pleochroism strong, *a* deep cendre blue, *c* pale greenish yellow. Indices of refraction (Na) $\omega = 1.691$, $\epsilon = 1.641$ (Berman); $\omega = 1.692$, $\epsilon = 1.640$ (Foshag).

RELATIONSHIPS

Except for the complex and anomalous mineral boracite, bandylite is the only reported borate and chloride mineral. It differs essentially from boracite in type in being a well defined double salt borate-chloride rather than a chloro-borate. In the same way it differs from such minerals as fluoborite, $6\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 6(\text{F}, \text{OH})$ and avogadrite $(\text{K}, \text{Cs})\text{BF}_4$, which are borofluorides and not double salts.

The mineral bandylite, however, shows some interesting relationships to the artificial borate-chloride of sodium.³



Both of these minerals are tetragonal.

Both antofagastite and bandylite are obviously secondary products. They are usually intimately associated with atacamite, which is probably slightly later than the antofagastite. Certain areas of bandylite are surrounded by antofagastite but there is no residual copper borate to suggest that the chloride is derived from the double salt by aqueous decomposition. It appears more likely that both minerals are essentially contemporaneous and have deposited from solutions in which copper chloride was in excess. The atacamite, sparingly associated with these minerals, is sometimes earlier but usually is later than these two minerals.

³ This salt has been found occurring naturally at Borax Lake, Lake Co., California, by Dr. W. A. Gale and Mr. M. Vonsen, and will shortly be described under the mineral name teepelite. The artificial salt is described by John E. Teeple: *The Industrial Development of Searles Lake Brines*, p. 33, 1929.

A SMALL SET OF GRIDS FOR THE DETERMINATION OF NON-OPAQUE MINERALS

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DETERMINATIVE SCHEME

The principle of the determinative grids has been described elsewhere¹ as a novelty. I have learned, however, through a review of that paper,² that my "invention" was proposed fifteen years ago by Gray,³ a mining engineer in Johannesburg, South Africa. I take this opportunity to acknowledge his priority in the matter.

Not only the amateur mineralogist, but the professional as well, will agree that the determination of minerals is always a delicate, sometimes a baffling, problem. The main reason for this is that the available determinative tables are based on a certain number of distinguishing criteria, taken up in an imposed order. But, the specimen to be identified may or may not exhibit particularly well the properties on which the very first subdivisions are made. For instance, the excellent tables of Larsen and Berman require, at the outset, a knowledge of the optical character of the mineral, as biaxial positive, uniaxial negative. If no good interference figure can be obtained, it becomes extremely difficult to make use of the determinative data recorded in the tables. Any kind of table constructed on the dichotomous principle is similarly handicapped.

Every specimen shows certain properties better than others; they are those on which the determination should rest. The logical consequence of this is that one should have as many different tables as there are different orders in which the various properties of a mineral can be listed. If we were satisfied to use only twenty properties, the number of desirable tables would be equal to the number of permutations of 20, that is to say *factorial 20*, or more than two quintillion. No library in the

¹ Donnay, J. D. H., *Système de grilles pour la détermination des minéraux: Annales Soc. géol. Belgique*, vol. 59, B, pp. 250-257, 1936.

² *Min. Abstr.*, vol. 6, 431, 1937. In this review the principle of the grids is misunderstood, in that a hole is said to stand for a property ("A series of cards with perforations corresponding to various characters are superposed"), whereas it actually represents a mineral, and each grid corresponds to a property. This error has been repeated in another review (*N. Jb. Min.*, Ref. I, 1937, p. 121).

³ Gray, C. J., A new method of using the physical characteristics of minerals for their identification: *Trans. Geol. Soc. S. Africa*, vol. 23, pp. 114-117, 1920 (1921). The set comprises 361 minerals, for which 66 grids are available.

A recent patentability search has revealed the existence of a patent, taken in 1915, by Horace Taylor of Brookline, Mass., describing an identical "Selective device" applied to the determination of birds (*added while in press*).

world could house such a collection of books. The set of grids enables one to construct at will and instantaneously any one of these multitudinous determinative tables.

In the small model recently placed on the market, a grid is a sheet of cardboard, about 7 by 3 inches, on which 45 vertical columns of 10 figures each (0 to 9) are printed, the columns being numbered from 1 to 45 along the lower margin of the card. Every one of the 450 figures stands for a mineral, which can be looked up in the index. For example: 0 in column 1 represents *acmite*; 0 in column 45, *barite*; 9 in column 38, *zircon*. Each card corresponds to a property; it is labelled accordingly, for instance *Red or reddish*. On that card all the figures that represent red or reddish minerals are punched out (hence the name "grid"). On superposing various grids, corresponding to several properties observed on a specimen, some holes will be left open: they indicate all the minerals that possess all these properties. After a sufficient number of properties have been determined (and it does not matter which ones), the number of holes left will be reduced to one (the one that stands for the mineral name sought) or to none (in which case the mineral is not among the 450 included in the grids, or a mistake has been made in the determination of the properties, or again there is an error in the construction of the grids). The punching of the cards is done mechanically so that perfect register is insured when the grids are stacked and held against the light.

The present model⁴ has been designed to meet the needs of petrographers, mining engineers, oil geologists, students in mineralogy, and mineral collectors. It covers 450 non-opaque minerals, including all the common species, all the petrographically important minerals (igneous, metamorphic, and sedimentary) whether common or not, and about one hundred additional minerals carefully selected in order to give a comprehensive representation of the less common groups of non-opaque species.

CHOICE OF DETERMINATIVE PROPERTIES

The grids are numbered from 001 to 254. They are also labelled according to the properties they represent. The list of determinative properties is given in Table 1. Further grids will be prepared from time to time (extinction angle, twinning, etc.)

⁴ A larger model, covering all (ca. 1250) non-opaque minerals, was exhibited at the Cincinnati meeting of the Geological Society of America (Donnay and Mélon, *Am. Mineral.*, vol. 22, p. 218, 1937; abstract). It had 210 grids, 55 by 37 cm., which were hand-punched. Six copies of this set were made, and sold. No way was found of manufacturing it inexpensively and, unless a sufficient number of requests are received, further sets of this type will not be constructed.

TABLE 1. DETERMINATIVE PROPERTIES

I. OCCURRENCE

- 001. Rock forming minerals
- 002. River concentrates
- 003. Powdery minerals

II. STRUCTURE

- 004. Fibrous
- 005. Radiating
- 006. Micaceous or flaky
- 007. Lamellar or columnar

III. CRYSTAL HABIT

- 008. Equidimensional
- 009. Prismatic or acicular
- 010. Tabular
- 011. Pyramidal

IV. HARDNESS

- | | |
|---------------------------------|---------------------------------|
| 012. H less than 1 | 027. H more than 1 |
| 013. H less than $1\frac{1}{2}$ | 028. H more than $1\frac{1}{2}$ |
| 014. H less than 2 | 029. H more than 2 |
| 015. H less than $2\frac{1}{2}$ | 030. H more than $2\frac{1}{2}$ |
| 016. H less than 3 | 031. H more than 3 |
| 017. H less than $3\frac{1}{2}$ | 032. H more than $3\frac{1}{2}$ |
| 018. H less than 4 | 033. H more than 4 |
| 019. H less than $4\frac{1}{2}$ | 034. H more than $4\frac{1}{2}$ |
| 020. H less than 5 | 035. H more than 5 |
| 021. H less than $5\frac{1}{2}$ | 036. H more than $5\frac{1}{2}$ |
| 022. H less than 6 | 037. H more than 6 |
| 023. H less than $6\frac{1}{2}$ | 038. H more than $6\frac{1}{2}$ |
| 024. H less than 7 | 039. H more than 7 |
| 025. H less than $7\frac{1}{2}$ | 040. H more than $7\frac{1}{2}$ |
| 026. H less than 8 | 041. H more than 8 |

042. Minerals whose hardness is given in the literature or could be estimated.
(This grid eliminates all minerals whose hardness probably cannot be determined.)

V. SPECIFIC GRAVITY

- | | |
|-----------------------|-----------------------|
| 043. G less than 2 | 051. G more than 2 |
| 044. G less than 2.5 | 052. G more than 2.5 |
| 045. G less than 2.9 | 053. G more than 2.9 |
| 046. G less than 3.33 | 054. G more than 3.33 |
| 047. G less than 4 | 055. G more than 4 |
| 048. G less than 4.5 | 056. G more than 4.5 |
| 049. G less than 5 | 057. G more than 5 |
| 050. G less than 6 | |

- 058. G between 6 and 7
- 059. G between 7 and 8
- 060. G more than 8

VI. REFLECTED COLOR

061. Yellow, gold, or greenish yellow	068. Blue
062. Brown or brownish	069. Green or blue
063. Red or reddish	070. Violet or purple
064. Orange	071. Blue or violet
065. Yellow, orange, brown, or red	072. Colorless or white
066. Green	073. Black
067. Green, brown, or yellow	074. Gray

VII. PLEOCHROISM

075. Nonpleochroic
076. Pleochroic

Remarks: (1) Always use one of these two grids jointly with grids indicating transmitted color (or colors).

(2) Faintly pleochroic minerals are recorded on both 075 and 076. The two grids may be superposed to indicate faint pleochroism.

VIII. TRANSMITTED COLORS

077. Yellow	084. Blue
078. Brown or brownish	085. Green or blue
079. Red or reddish	086. Violet
080. Orange	087. Blue or violet
081. Yellow, orange, brown, or red	088. Colorless
082. Green	089. Black
083. Green, brown, or yellow	090. Gray or neutral

IX. CLEAVAGE

091. No distinct cleavage
092. Cleavage in at least 1 direction
093. Cleavage in at least 2 directions
094. Cleavage in at least 3 directions
095. Cleavage in at least 4 directions

X. REFRACTIVE INDICES

At least one refractive index has the following value:

096. n less than 1.46	105. n more than 1.46
097. n less than 1.50	106. n more than 1.50
098. n less than balsam	107. n more than balsam
099. n less than 1.60	108. n more than 1.60
100. n less than 1.66	109. n more than 1.66
101. n less than 1.70	110. n more than 1.70
102. n less than 1.74	111. n more than 1.74
103. n less than 1.78	112. n more than 1.78
104. n less than 1.88	113. n more than 1.88

XI. BIREFRINGENCE

114. Isotropic

115. Anisotropic

The maximum birefringence B of the mineral has the following value:116. B less than .0035124. B more than .0035117. B less than .0095125. B more than .0095118. B less than .0185126. B more than .0185119. B less than .0275127. B more than .0275120. B less than .0365128. B more than .0365121. B less than .0545129. B more than .0545122. B less than .100130. B more than .100123. B less than .200131. B more than .200

XII. OPTICAL SIGN

132. Uniaxial

134. Positive

133. Biaxial

135. Negative

XIII. OPTIC ANGLE $2V$ 136. $2V$ less than 30° 139. Minerals for which $2V$ is given in literature. This grid eliminates all minerals for which $2V$ probably cannot be determined.137. $2V$ between 30° and 60° 138. $2V$ more than 60°

XIV. DISPERSION

140. r smaller than v 141. r greater than v

142. No dispersion

XV. CRYSTALLINITY

143. Amorphous

148. One 6-fold rotation axis

144. Isometric system

149. Orthorhombic system

145. Tetragonal system

150. Monoclinic system

146. Hexagonal system (*sensu vasto*)

150.1. Monoclinic or orthorhombic

147. One 3-fold rotation axis only

151. Triclinic system

XVI. FUSIBILITY

152. F less than 2158. F more than 1153. F less than 3159. F more than 2154. F less than 4160. F more than 3155. F less than 5161. F more than 4156. F less than 6162. F more than 5157. F less than 7 (still fusible)163. F more than 6 (infusible)

XVII. SOLUBILITY

164. Soluble in water

165. Soluble in HCl, HNO₃, or aqua regia

166. Insoluble in these acids

XVIII. CHEMISTRY

Ag (167, 211)—Al (168, 212)—Arsenate (169, 213)—Arsenide, telluride or Se (170, 214)—Ba or Sr (171, 215)—Bi (172, 216)—Bo (173, 217)—Br, Cl, or I (178, 222)—C, in carbonate (174, 218)—C, not as CO₂ (175, 219)—Ca (176, 220)—Cd (177, 221)—Cl, Br, or I (178, 222)—Co or Ni (179, 223)—Cr (180, 224)—Cu (181, 225)—Cs, Rb, or Li (182, 226)—F (183, 227)—Fe (184, 228)—Fe, ferrous (185, 229)—Fe, ferric (186, 230)—H₂O in closed tube (187, 231)—Hg (188, 232)—I, Cl, or Br (178, 222)—K (189, 233)—Li, Cs, or Rb (182, 226)—Mg (190, 234)—Mn (191, 235)—Mo (192, 236)—N, in nitrate (193, 237)—Na (194, 238)—Nb or Ta (195, 239)—NH₄ (196, 240)—Ni or Co (179, 223)—P, in phosphate (197, 241)—Pb (198, 242)—Rare earths (199, 243)—Rb, Cs, or Li (182, 226)—S, in sulfate (200, 244)—S, in sulfide (non oxidized) (201, 245)—Sb (202, 246)—Se, arsenide, or telluride (170, 214)—Si, or Si in silicate (203, 247)—Sn (204, 248)—Sr or Ba (171, 215)—Telluride, arsenide, or Se (170, 214)—Ta or Nb (195, 239)—Ti (205, 249)—U (206, 250)—V (207, 251)—W (208, 252)—Zn (209, 253)—Zr (210, 254).

Remark—Positive test: first number. Negative test: second number.

A wide range of properties can be used, many of which serve only as confirmatory criteria in the usual determinative tables. They can be used in any order. The properties that show best should be given precedence. Any amount of information is of value. For instance, such properties as hardness, specific gravity, refractive index, birefringence, fusibility, can be determined with small or great accuracy; one may always "frame" the determined value between any two limits that will allow for the possible error. Example: *hardness less than 5 1/2* (grid 021) and *more than 2 1/2* (grid 030), or *hardness less than 4* (grid 018) and *more than 3* (grid 031). For chemical properties, negative as well as positive tests have a determinative value. Example: the mineral *contains aluminum* (use grid 168) or *does not contain aluminum* (use grid 212).

At any time during the determinative procedure, the number of possibilities left indicate the progress made. The grids are also a guide in the choice of further determinative tests. Example: in order to find out whether the knowledge of a certain additional property (say, the solubility in acids) would be useful for the progress of the determination, simply take the grid that corresponds to that property and place it on the stack already available; if the grid extinguishes many holes, it is advantageous to determine the property; if not, another grid may point to a more effective property.

Some grids should be used with caution. Example: *No distinct cleavage*. It is hard to say that a mineral has no cleavage from examining one specimen only. The cleavage may not show, or one may not succeed in producing it. The difficulty has been somewhat minimized by including minerals with imperfect cleavage in the grid, which is accordingly

labelled "No *distinct* cleavage." Yet one must keep in mind that negative criteria are less certain than positive ones.

Colors in reflected light (in the hand specimen). Provision is made for indefinite colors (grids 065, 067, 069). Such grids do not have as much determinative value as the more specific ones. If you are able to detect a mixture of two colors in your specimen (say, bluish green or greenish blue) use both *blue* (grid 068) and *green* (grid 066) in order to make use of your observation to full advantage. Colors of streaks and powders are included.

Pleochroism and transmitted colors (in polarized light). Either the grid *Pleochroic* (076) or the grid *Non pleochroic* (075) should always be used in conjunction with grids for transmitted colors. Feebly pleochroic minerals have been included in both grids 075 and 076; if the pleochroism is obviously weak, the two grids can be used jointly. Similarly a mineral with a birefringence close to .0095 (quartz, e.g.) is entered on both grid 117 (*B less than .0095*) and grid 125 (*B more than .0095*). In all such cases, where the determined value of a property is on the border line between two grids, both may be used jointly, with circumspection, of course, since this practice implies a fairly accurate determination of the property in question.

Hardness and 2V. The grid *Hardness in literature* (042) may be used when the hardness is so easy to find that there is no doubt it has been determined by previous observers and recorded in the literature. This eliminates all minerals on which H never was determined. The same remark applies to grid 139 (*2V in literature*).

Dispersion. On the grid *No dispersion* only those minerals are "punched out" for which the absence of dispersion has been recorded in the literature. This grid shows that data on dispersion are lacking for a great many species; it is not safe to use it for determinative purposes.

Chemistry. Only the main constituents of the mineral are taken into account, namely those that are expressed by its chemical formula. Impurities that may occur in traces or in small amounts should be disregarded.

General recommendation. Do not feel obliged to use a property that does not show well; restrict your choice to reliable characters.

EXAMPLES OF DETERMINATION

N.B.—The names of the minerals given as examples will be found in the appendix to this paper under their key numbers. Before looking them up try to identify the "unknowns" from the properties indicated.

Example I. The specimen is *blue* (grid 068), its *G is less than 2.9* (grid 045), its *H more than 7.5* (grid 040). Mineral 1-8.

Example II. *Blue* (068), *H less than 2.5* (015), *water in the closed tube* (187), *soluble in acids* (165), *ferrous iron* (185). Mineral 9-17.

Example III. If you suspect what the specimen is, you test for *P, in phosphate* (197), *ferrous Fe* (185), *H less than 2.5* (015). Mineral 9-17.

Example IV. *Amorphous* (143), *orange* (064), *G more than 5* (057). Mineral 8-23.

Example V. *Green* (066), *one 6-fold rotation axis of symmetry* (148), *G between 6 and 7* (058). Mineral 7-18.

Example VI. *Soluble in water* (164), *isotropic* (114), *n less than 1.50* (097). Mineral 8-30.

Example VII. *Isometric* (144), *red* (063), *H less than 4* (018), *F less than 4* (154), *F more than 2* (159). Mineral 2-24.

Example VIII. A mineral is found in a rock (001), it is *micaceous* (006), *green* (066), *hexagonal sensu vasto* (146), its *G is less than 2.5* (044). Mineral 1-20.

Example IX. A mineral may be determined by different sets of simultaneous properties. (a) *Isometric* (144), *H less than 5* (020), *rock forming mineral* (001). Or, (b) *Equidimensional* (008), *isotropic* (114), *n less than 1.46* (096), *contains Ca* (176). Or, (c) *H more than 3* (031), *cleavage in at least 4 directions* (095), *G less than 3.33* (046), *no water in closed tube* (231), *soluble in acids* (165), *contains F* (183). Mineral 3-29.

Example X. (a) The mineral is determined by optical methods. *Pleochroic* (076), *yellow* (077) and *colorless* (088) in transmitted light, *n more than 1.88* (113), *uniaxial* (132), *positive* (134). (b) The mineral occurs as a massive specimen. *H more than 6* (037), *H less than 7* (024), *G between 7 and 8* (059) and *G between 6 and 7* (058) (these two grids are used jointly because the *G* is very close to 7), *insoluble in acids* (166). (c) The unknown occurs in good crystals. *Rock forming mineral* (001) *tetragonal* (145), *black* (073), *no distinct cleavage* (091). (d) The mineral is a rounded pebble. A simple chemical test, found to be positive, permits you to use grid 204, which suffices to determine the mineral. In all four cases (a, b, c, d) the mineral is 1-31.

Example XI. This last example is given to show how it is possible to realize the progress of the determination as the grids are used. The unknown will be determined by three different methods.

(a) BY MEANS OF THE POLARIZING MICROSCOPE AND A PREPARATION IN CANADA BALSAM.

Pleochroic (Grid 076): there are 185 minerals that possess this property. Three distinct hues of pleochroism, *blue* (084), *violet* (086), *gray or neutral* (090): 10 minerals remain. The *refractive index is greater than that of*

Canada balsam (107): 9 possibilities remain. *At least one index is less than 1.70* (101): 8 minerals are left. *Anisotropic* (115): the 8 holes are left open. *Birefringence more than .0095* (125): 7 minerals left. *Birefringence less than .0275* (119): 6 minerals left. *Biaxial* (133): the 6 possibilities are unchanged. *Negative* (135): 5 minerals are left. *Angle of the optic axes between 30° and 60°* (137): 4 minerals now remain. *Dispersion, r smaller than v* (140): the same 4 possibilities are unchanged. They are: 2-13, 2-20, 3-3, 3-43.

(b) BY CHEMICAL TESTS.

In this case a chemical determination would be quite laborious. Assuming that one has ascertained that the unknown is *insoluble in acids* (grid 166), that it is a *silicate* (grid 203), that it contains *Al* (grid 168), *Na* (194), *Mg* (190), *Fe* (184), and even *ferrous Fe* (185), which amounts to a rather complete qualitative analysis, all that information will still leave 17 possibilities open. A simple test, *no water in the closed tube* (grid 231), will help materially in the determination—closing all the 17 holes but 4. The choice is now limited to: 0-5, 1-1, 2-20, 3-43.

(c) BY SIMPLE PHYSICAL TESTS.

As compared with the above determinations, let us try to identify the unknown by means of its macroscopic properties, with none but the simplest tests.

The mineral is blue-black. Use grids 068 (*blue*) and 073 (*black*). Its *H* is *less than 7* (grid 024) and *more than 6* (grid 037). These grids immediately restrict the choice to 3 minerals. If the specimen permits recognition of the crystal system (*monoclinic*, grid 150), the determination is completed. If one hesitates between monoclinic and orthorhombic, grid 150.1 (*Monoclinic or orthorhombic*) may be used and found just as effective. If the symmetry is not apparent, an approximate value for the specific gravity may be obtained (heavy liquids, balance, or sense of heft) and grid 046 (*G less than 3.33*) used. This also leads to the result. Or again, the fusibility (3) may be tested with the blowpipe; grids 154 (*F less than 4*) and 159 (*F more than 2*), added to the first four, make the determination complete. And if the fusibility is difficult to estimate, surely the intense yellow flame cannot be missed—then grid 194 (*Na*) will prove sufficient. Mineral 3-43.

MATERIAL PRESENTATION

The grids are made of Manila cardboard, $7\frac{3}{8}$ by $3\frac{1}{4}$ inches. They are contained in a special filing box, $2\frac{1}{2}$ inches deep, made of cedar wood, with shellac finish, corners interlocked and glued, hinges and fastener nailed, lid cut obliquely to facilitate handling of cards. Twenty labelled

guides (buff Bristol tabs) separate the groups of properties. The index of minerals is printed twice: on ten Manila cards, as permanent reference, and in tabular form, for desk use.

ACKNOWLEDGMENTS

Most of the data recorded in the grids are taken from Larsen and Berman. Dana has been especially useful for the data on colors in reflected light. The limits adopted for the ranges in birefringence are those proposed by Winchell. A number of standard textbooks on mineralogy have been occasionally consulted and many references to the original descriptions had to be made.

It is a pleasure to tender my best thanks to Dr. J. Mélon, of the University of Liège, Belgium, who helped me prepare the data for the large model and gave many valuable suggestions as to the selection of determinative properties.

Appendix

INDEX TO MINERALS

0-1, Acmite. 0-5, Aegirite. 0-45, Barite. 1-1, Barkevikite. 1-8, Beryl. 1-20, Brucite. 1-31, Cassiterite. 2-13, Cordierite. 2-20, Crossite. 2-24, Cuprite. 3-3, Dumortierite. 3-29, Fluorite. 3-43, Glaucothane. 7-18, Pyromorphite. 8-23, Stibiconite. 8-30, Sylvite. 9-17, Vivianite. 9-38, Zircon.

GARNETS FROM VESICLES IN RHYOLITE NEAR ELY, NEVADA

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The occurrence of garnet in rhyolite near Ely, Nevada, has been described by Spencer¹ and by Melhase.² The youngest igneous rock in the Ely district is a tertiary (probably pliocene) rhyolite. In the area north of Lane Valley, marked "garnet fields" on the map of the Ely quadrangle, the rock is "characterized by more or less globular vesicles" lined with a continuous coating of white glassy quartz. Garnet crystals from a few millimeters to over 10 millimeters in diameter are implanted on this coating or partly intergrown with the quartz. No other minerals were found in the vesicles. The garnet crystals are deep red, very shiny, and perfectly clear. They show the trapezohedron (211) with occasional faces of the dodecahedron.

Through the courtesy of Mr. John Melhase of Berkeley the writer obtained specimens showing the garnets in vesicles in rhyolite. A grant for the chemical analysis from the Board of Research of the University of California is gratefully acknowledged.

After a preliminary spectroscopic examination by Dr. T. G. Kennard of Claremont, California, which showed no chromium and only a minute trace, probably 0.00x% of titanium, the garnet was analyzed by W. H. Herdsman with the results given below.

TABLE 1. ANALYSIS OF GARNET FROM RHYOLITE NEAR ELY, NEVADA

		molecular quotients	
SiO ₂	36.28	.6041	6041
Al ₂ O ₃	21.27	.2087	2103
Fe ₂ O ₃	0.24	.0015	
FeO	29.46	.4101	
MnO	11.96	.1686	5917
MgO	0.14	.0035	
CaO	0.53	.0095	
H ₂ O-105°C	nil		
H ₂ O+105°C	nil		
	99.88		
	RO:R ₂ O ₃ :SiO ₂		
	2.82: 1 :2.87		

The departure of the molecular ratio from the ideal garnet formula, 3RO·R₂O₃·3SiO₂, is similar to the discrepancies that have been found

¹ Spencer, A. C., *U. S. Geol. Survey, Professional Paper* 96, p. 42, 1917.

² Melhase, John, *The Oregon Mineralogist*, vol. 2, no. 11, p. 6, 1934.

in many garnet analyses. Fleischer³ has recently pointed out that this sort of a departure might be due to the presence of titanium in the garnet or to the misdetermination of FeO as Fe₂O₃. This will not explain the difference in the present case. Assuming 96 oxygens in the unit cell, one may calculate that there are on the average 23.37 R'', 16.60R''', and 23.86 Si in a unit cell of this Ely garnet. If, as has been suggested, Al is placed partly in R'' and in Si positions then the discrepancy may be greatly reduced.

The specific gravity of the garnet was determined on selected fragments by pycnometer, giving the value 4.26.

The lattice constant, as determined from a powder pattern corrected with halite, using a cassette of 8 inch radius and Mo radiation screened with zirconium oxide, is $11.531 \pm 0.010 \text{ \AA}$.

The refractive indices were determined on several cut and polished prisms by the minimum deviation method, using a small Leitz monochromator.

$$\begin{array}{ccc} N_{\text{Li}} & N_{\text{Na}} & N_{\text{Ti}} \\ 1.820 & 1.824 & 1.828 \\ N_{\text{Na}} - N_{\text{Li}} = 0.004 & & N_{\text{Ti}} - N_{\text{Na}} = 0.004 \end{array}$$

Fleischer⁴ has recently discussed the relations of composition and properties in the garnet group and from the properties of the end members as given by him one may calculate the properties of a complex garnet. The second column of Table 2 gives the results of such a calculation.

TABLE 2. CALCULATED AND OBSERVED PROPERTIES OF GARNET FROM RHYOLITE
NEAR ELY, NEVADA

	Observed	Calculated	Difference
Specific gravity	4.26	4.27	0.01
Lattice constant	11.531 \AA	11.529 \AA	0.002 \AA
N_{Na}	1.824	1.822	0.002

The observed values of all properties agree within the limits of error with the calculated values. Nevertheless an accurate determination of the composition cannot be made from the properties of garnets of this type. The discrepancy of only 0.002 in the index determination, for instance, corresponds to a difference in the proportion of the spessartite molecule of about 7%.

The only other analysis of garnet in lithophysae in rhyolite known to the writer is one of material from near Nathrop, Colorado, published by

³ Fleischer, M., The relation between composition and physical properties in the garnet group: *Am. Mineral.*, vol. 22, pp. 751-759, 1937.

⁴ *Op. cit.*

Cross.⁵ This garnet is similar in color, habit and size to that found near Ely. It is even richer in manganese and is associated with sanidine, quartz and topaz in the lithophysae, whereas the vesicles in the Ely rhyolite carry only quartz and garnet.

Garnets rich in the spessartite molecule or belonging to the almandite-spessartite series are characteristic of granite pegmatites. A pegmatite garnet closely similar to the Ely garnet in composition has been recorded by Shannon⁶ near Avon, Latah County, Idaho.

Table 3 shows the comparison of the composition of the Ely garnet with those just mentioned.

TABLE 3. COMPOSITION OF GARNETS FROM RHYOLITE VESICLES AND FROM GRANITE PEGMATITE

Garnet	Pegmatite Avon, Idaho	Rhyolite Ely, Nevada	Rhyolite Nathrop, Colorado
Almandite	63.0	69.3	31.3
Spessartite	32.8	28.5	65.4
Pyrope	4.2	.6	—
Grossularite	—	.8	2.3
Andradite	—	.8	1.0

⁵ Cross, W., On the occurrence of topaz and garnet in lithophysae of rhyolite: *Am. Jour. Sci.*, 3rd series, vol. 31, pp. 432-438, 1886.

⁶ Shannon, E. V., Note on garnet from a pegmatite in Idaho, *Am. Mineral.*, vol. 7, pp. 171-173, 1922.

TAENIOLITE FROM MAGNET COVE, ARKANSAS*

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INTRODUCTION

Taeniolite is an exceedingly rare lithium-magnesium mica, first described from Narsarsuk on the Firth of Tunugdliarfik in southern Greenland.¹ It has also been mentioned by Fersman² without description as occurring in laminae resembling the Greenland mineral in the Kola Peninsula, U. S. S. R.

In November 1936, Mr. Miser secured specimens of a mica-like mineral at Magnet Cove, Arkansas, from Joe W. Kimzey of Magnet, Arkansas, and from J. S. Smith of Crystal Springs, Arkansas. Additional material was secured in February 1937 from Lawton D. Kimzey of Magnet and again in November 1937 when the locality was visited by Mr. Miser, Mr. Kimzey, W. T. Schaller and C. S. Ross.

The Arkansas mineral resembles sericitic muscovite with an unusually silky luster. Optical examination, and qualitative chemical tests indicated that it was not muscovite, and that it contained essential amounts of lithium. For this reason the mineral was analyzed (by R.E.S.) and proved to be the rare mineral taeniolite. Its discovery in Arkansas in amounts sufficient for a careful analysis permitted its chemical composition to be definitely established.

The Arkansas taeniolite was discovered in 1936 by Lawton D. Kimzey in the course of prospecting for rutile for the American Titanium & Alloy Co. on the Adam Smith property about 1 mile north of Magnet Post Office. It has been found in several openings—one a shaft 50 feet deep, a pit 55 feet long, 4 feet wide, and 15 feet deep, another pit 40 feet long, 12 feet deep, and 4 feet wide, and a small shaft-like pit—within an area measuring 400 (north-south) by 200 feet, on the crest of a wooded hill. From these openings the total amount of taeniolite, obtained and placed on the dumps with the other material from the pits, is estimated by Mr. Kimzey to be about a ton. The taeniolite occurs as irregular veins and pockets as much as a foot wide in red and yellow clay and a quartzite-like rock which is a recrystallized novaculite—a variety of chert of Devonian age. The novaculite, where the taeniolite is present,

* Published by permission of the Director, U. S. Geological Survey. Presented at the Symposium on Geochemistry, meeting of the American Chemical Society in Rochester, N. Y., September 9, 1937.

¹ Flink, Gustav, *Taeniolite: Meddeleser om Grönland: Fire og tyvende Hefte*, vol. 24, pp. 115–120, Kjobenhaven, 1901.

² Fersman, A. E., *Minerals of the Kola Peninsula: Am. Mineral.*, vol. 11, p. 295, 1926.

varies in texture from almost chertlike to very coarse grained with interlocking grains and contains numerous vesicular cavities up to several millimeters in diameter. The coarsest rock contains quartz grains about 4 millimeters in length, many of which are smoky in color and reveal crystal faces. A small area of nepheline syenite lies several hundred feet to the north, and a part of the main mass of the Magnet Cove igneous rocks outcrop about $\frac{1}{4}$ mile to the southwest of the taeniolite locality. These igneous rocks were intruded—apparently in early Upper Cretaceous time—into closely folded sedimentary strata of Ordovician, Silurian, Devonian and Pennsylvanian age.³ The igneous rocks caused very noticeable metamorphism in the intruded sedimentary strata, accompanied by the introduction of a large group of unusual minerals, among which is taeniolite.

The minerals directly associated with taeniolite are quartz, dickite, rutile, and probably brookite. The taeniolite occurs as loose, friable masses associated with roughly shaped quartz crystals, or with quartz and dickite along fracture planes, or joint cracks, and also as disseminated flakes in the quartzite-like rock. One type grades into another. The loose friable taeniolite is somewhat coarser grained than the disseminated material, and forms plates that vary from 0.04 to 0.2 and average about 0.15 millimeter in diameter. The thickness is difficult to estimate, but is a very small fraction of a millimeter. These plates have an irregular, commonly lobate outline, and only very rarely show a roughly hexagonal outline.

The Arkansas material does not occur in the band or strip-like form that suggested the name taeniolite for the Greenland material.

PHYSICAL AND OPTICAL PROPERTIES

The cleavage is basal as in all micas.

The density was determined on a 0.4 gram sample by the pycnometer method, using boiled and cooled distilled water. Air was drawn off by suction and the sample allowed to stand overnight to insure complete removal of air. The density was found to be 2.819 and the specific gravity 2.828, referred to water at 25°C. Mauzelius⁴ found the specific gravity of taeniolite from Greenland to be 2.86 at 16°C. by weighing in benzol.

³ The following reports, illustrated by geologic maps, describe the geology of the part of the Magnet Cove district in which the taeniolite was found:

Williams, J. F., The igneous rocks of Arkansas: *Arkansas Geol. Survey, Ann. Report for 1890*, vol. 2, 1891.

Parks, Bryan and Branner, G. C., A barite deposit in Hot Spring County, Arkansas: *Arkansas Geol. Survey, Information Circular* 1, 1932.

⁴ Flink, G., *Medd. om Grönland*, vol. 14, p. 234, 1898; vol. 24, p. 115, 1901.

Although nearly white or colorless in places, much of the material is stained brownish by iron oxide. The luster is pearly.

Under the microscope the flat-lying plates are isotropic or slightly birefracting where warped. The optical properties, determined by Dr. C. S. Ross of the U. S. Geological Survey, are as follows: Approximately uniaxial, optically negative, $\alpha=1.522$, $\beta=1.553$, $\gamma=1.553$; all $\pm .002$; birefringence 0.031.

CHEMICAL ANALYSIS

Enough of the taeniolite from Magnet Cove, Arkansas, for a thorough analysis was separated from associated quartz by means of heavy solutions. The process of analysis was briefly as follows:

TABLE 1. ANALYSES OF TAENIOLITE

	Magnet Cove, Ark. (Stevens, analyst)	Greenland (Mauzelius, analyst)
SiO ₂	58.82	52.2
Al ₂ O ₃	1.29	2.7
Fe ₂ O ₃	0.40	—
FeO	0.24	0.6
MgO	19.18	19.1
CaO	None	—
Li ₂ O	3.10	3.8
Na ₂ O	0.64	1.8
K ₂ O	10.44	11.5
Rb ₂ O	None	—
Cs ₂ O	None	—
H ₂ O—	0.09	—
H ₂ O+	0.59	8.7*
TiO ₂	0.11	—
F	8.56	—
Cr ₂ O ₃	Trace	—
MnO	None	—
BaO	None	—
	<hr/> 103.46	<hr/> 100.4
Minus O = F	3.61	
	<hr/> 99.85	

* Ignition loss.

Silica and fluorine in a one gram sample were separated by the Berzelius method as modified by Hoffman and Lundell,⁵ silica was then obtained by dehydration in the usual way, and fluorine determined nephelometrically.⁶ A trace of chromium was noted in the sodium carbonate leach.

Alkalies were extracted from a half gram sample by the J. Lawrence

⁵ Hoffman, J. I., and Lundell, G. E. F., *Bur. Standards J. Research*, vol. 3, p. 581, 1930.

⁶ Stevens, R. E., *Ind. Eng. Chem., Anal. Ed.*, vol. 8, p. 248, 1936.

Smith procedure. Potassium was separated and weighed as chloroplatinate and rare alkalies were shown to be absent in the insoluble chloroplatinate by methods described by Wells and Stevens.⁷ Lithium and sodium were separated by the Palkin⁸ method and weighed as sulphates.

The other constituents were determined by the methods of Hillebrand and Lundell⁹ after solution of a half gram sample in hydrofluoric and sulphuric acids and removal of hydrofluoric acid by several evaporations to fumes. Water was determined by the Penfield method using a glass tube with a flux of sodium tungstate.

The results of the analysis and those of Mauzelius¹⁰ on the Greenland taeniolite are given in Table 1.

The two analyses are enough alike to indicate that they are of the same mineral; the percentage of alumina in both analyses is unusually low for a mica, and the two analyses agree fairly well with regard to magnesia and the alkalies. The silica in the analysis by Mauzelius is probably low, however, due to volatilization as fluoride, and for this reason the two analyses do not calculate to the same formula. Fluorine was reported as probably present by Mauzelius but its interference with the silica determination could not be prevented in analyzing so small a sample (less than 0.1 gram).

The analyses show taeniolite to be a very unusual mica, as, unlike other micas, alumina is present only in small quantity. In spite of the absence of essential alumina taeniolite shows structural relationships in common with other micas. (See Fig. 1.)

FORMULA AND STRUCTURAL RELATIONSHIP TO OTHER MICAS

X-ray data for the micas, the brittle micas, and talc, indicate that they are built in layers; SiO_4 tetrahedrons are thought to be linked together in continuous sheets to give a composition of Si_4O_{10} . In the common micas aluminum partially substitutes for silicon, giving the structural group $\text{AlSi}_3\text{O}_{10}$. Two of these sheets of silicon-aluminum tetrahedrons are joined by octahedral groups of aluminum, magnesium, etc., to form a double layer. In the micas these double layers are held together by a large cation, potassium, calcium, or sodium; in talc the sheets are internally neutral and held together only by stray forces.

According to Bragg¹¹ the structural unit of a mica consists of $12(\text{O},$

⁷ Wells, R. C., and Stevens, R. E., *Ind. Eng. Chem., Anal. Ed.*, vol. 6, p. 439, 1934.

⁸ Palkin, J., *Am. Chem. Soc.*, vol. 38, p. 2326, 1916.

⁹ Hillebrand and Lundell, *Applied Inorganic Analysis*. John Wiley & Sons, New York, 1929.

¹⁰ Flink, G., *Medd. om Grönland*, vol. 24, p. 115, 1901.

¹¹ Bragg, W. L., *The atomic structure of minerals*: Cornell University Press, p. 38, 1937.

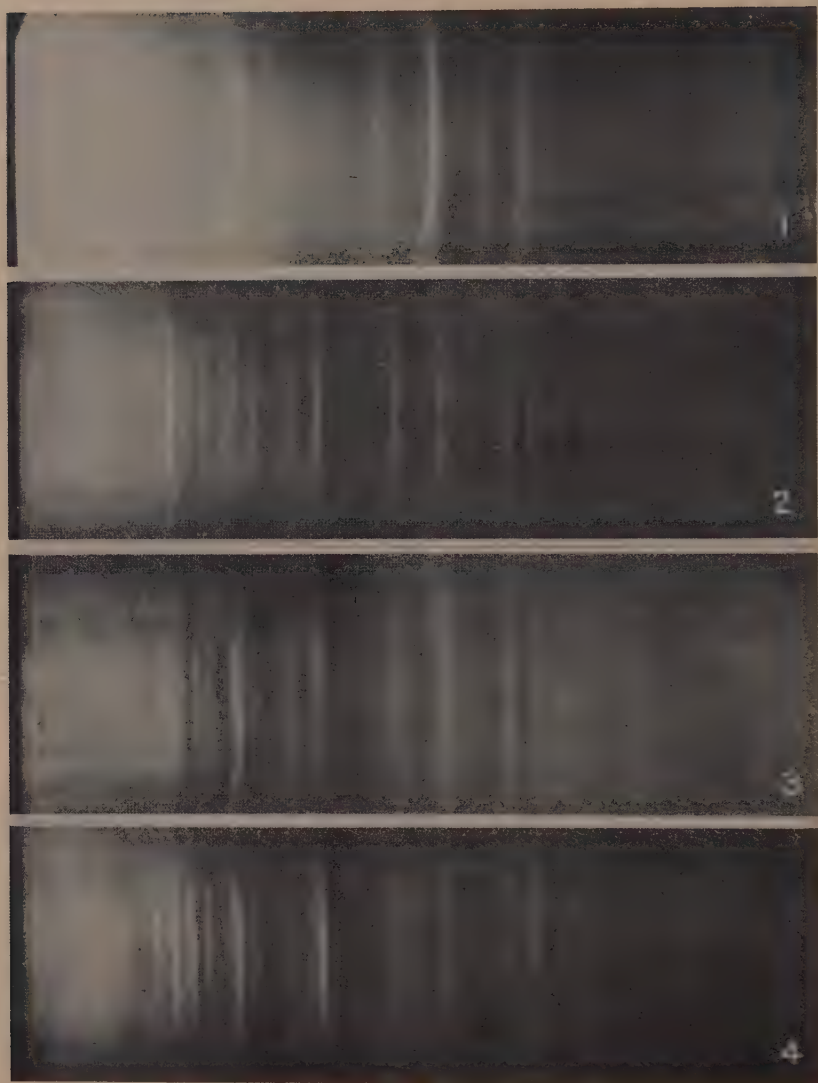


FIG. 1. X-ray powder photographs.
No. 1. Talc from New York.
No. 2. Taeniolite from Arkansas.
No. 3. Muscovite from New Mexico.
No. 4. Lepidolite from California.

OH, F) comprising 10 O, 2(OH, F); 4 tetrahedral positions, occupied by Si and Al; 2-3 octahedral positions, occupied by Mg, Al, Fe, Ti, Li; 0-1 positions for large cations, occupied by K, Ca, Na.

As the sum of anion equivalents is twenty-two (ten *bivalent* oxygens and two *univalent* hydroxyls or fluorines) the same number of cation equivalents are required for neutrality. For example, in muscovite, $\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$, the twenty-two anion equivalents are balanced by one equivalent of potassium, nine of aluminum, and twelve of silicon.

TABLE 2. CALCULATION OF THE FORMULA OF TAENIOLITE

	Analysis	Equivalent Ratios			Theory
SiO_2	58.82	3.903	15.91	Si_4	59.35
Al_2O_3	1.29	.076	.31		
TiO_2	0.11	.006			
FeO	0.24	.007	3.94		
MgO	19.18	.952		Mg_2	19.90
Li_2O	3.10	.207	.84	Li	3.69
		5.151	21.00		
Na_2O	0.64	.021			
K_2O	10.44	.222			
		.243	.99	K	11.63
$\text{H}_2\text{O}+$	0.59	.066			
F	8.56	.451			
		.517	2.11	F_2	9.38
$\text{Fe}_2\text{O}_3, \text{H}_2\text{O}-$	0.49				
	103.46				103.95
Minus O=F	3.61				3.95
	99.85				100.00

Therefore, in micas containing a univalent ion between the plates, usually potassium, the sum of equivalents in the octahedral and tetrahedral groups is twenty-one.

In Table 2 the formula of taeniolite is calculated in accordance with these relationships.

The formula for taeniolite is $\text{KLiMg}_2\text{Si}_4\text{O}_{10}\text{F}_2$. Although the equivalent ratio for lithium (.84) is slightly deficient for one lithium in the formula, a univalent ion in the octahedral group is essential for neutrality as one

potassium, two magnesium, and four silicon are definitely indicated. The ferric iron is not considered part of the mineral but merely pigmenting ferric oxide covering the mica plates. The small quantity of aluminum is not essential; it substitutes for silicon in the tetrahedral positions as well as for lithium and magnesium in octahedral positions. Deducting the formula for taeniolite ($\text{KLiMg}_2\text{Si}_4\text{O}_{10}\text{F}_2$) from the analysis, the remainder approximates the composition of muscovite ($\text{KAl}_2\text{AlSi}_3\text{O}_{10}(\text{OH})_2$), which is probably present in isomorphous mixture and accounts for the presence of aluminum in the mineral. Although a small part of the alumina may have been present as admixed clay, the analysis of Mauze- lius on the larger crystals of taeniolite, obtained from Greenland, shows that some alumina may be contained in the mineral taeniolite itself.

The relationship of muscovite, taeniolite, and talc may be indicated as follows:

	Large cation	Octahedral positions	Tetrahedral positions	$\text{O}_{10}(\text{OH}, \text{F})_2$
	0-1	2-3	4	12
Muscovite	K	Al_2	AlSi_3	$\text{O}_{10}(\text{OH})_2$
Taeniolite	K	LiMg_2	Si_4	O_{10}F_2
Talc	—	Mg_3	Si_4	$\text{O}_{10}(\text{OH})_2$

The similarity in structure of taeniolite, talc, and the two micas, muscovite and lepidolite, is shown in the *x*-ray photographs by the powder method, Fig. 1, for which the writers are indebted to George Tunell and C. J. Ksanda of the Geophysical Laboratory.

Because of the absence of essential aluminum, taeniolite is unique among the micas. The place of aluminum in the octahedral group is taken by lithium and magnesium. Furthermore, taeniolite is one of the few micas in which Si_4O_{10} constitutes the double layers, with little or no substitution by the group $\text{AlSi}_3\text{O}_{10}$.

LAPIS LAZULI FROM SAN BERNARDINO COUNTY, CALIFORNIA

AUSTIN F. ROGERS, *Stanford University, California.*

So far as known there is only one locality for lapis lazuli in the whole continent of North America. This locality is in San Bernardino County, California, on the north slope of the south fork of Cascade Canyon, which is a branch of San Antonio Canyon and distant about twelve miles from the city of Upland.

This occurrence first became generally known about 1912,¹ but it must have been discovered at a much earlier date. However, it is not mentioned by Henry G. Hanks in his list of California minerals in the Fourth Annual Report of the California State Mining Bureau, Sacramento, 1884. And no mention of it is made in G. F. Kunz's *Gems and Precious Stones of North America*, New York, 1890. Mr. F. J. Sperisen of San Francisco has called my attention to a statement in a book² by C. W. King which reads: "Although plentifully found [he is speaking of "sapphirus" or lapis lazuli] in China, and of late years in California, the product of both these countries is too full of pyrites and white veins to be available for the Glyptic art and is only good for calcination." This is the first mention of California lapis lazuli that I know of; it seems reasonably certain that the Cascade Canyon locality furnished the material.

The lapis lazuli was at first mistaken for a silver ore by prospectors. When its true nature became known, a company was formed to exploit it under the name "Lapis Lazuli Mining Company." The mining does not seem to have been a successful business venture, but some of the lapis has been mined and cut from time to time.

NATURE OF THE BLUE MINERAL

Lapis lazuli is a rock made up of a mixture of minerals, including the blue mineral to which it owes its attractiveness. The writer³ reported the blue constituent to be lazurite largely on account of its association with pyrite. Sterrett⁴ also called it lazurite.

Eakle⁵ stated: "The optical properties of the so-called lazurite from San Antonio Creek indicate that it is sodalite and not lazurite."

¹ The most complete article of this period is one by Gordon Surr, *Mining and Engineering World*, vol. 39, pp. 1153-4, 1913.

² *The Natural History of Gems or Decorative Stones*, London, 1867, footnote p. 273.

³ *School of Mines [Columbia] Quarterly*, vol. 33, p. 377, 1912.

⁴ *U. S. Geol. Surv., Min. Resources for 1913*, p. 675, 1914.

⁵ *California State Mining Bureau, Bull.* 91, p. 170, 1922.

Difference of opinion as to the nature of the blue mineral led the writer to a study of the material. Before the blue mineral is discussed in detail the other constituents of the lapis will be mentioned.

DESCRIPTION OF THE ROCK

The lapis lazuli is a blue to bluish gray, more or less banded rock. Often the blue mineral is concentrated in layers from one to 3 or 4 mm. thick as shown in the accompanying figure (Fig. 1).

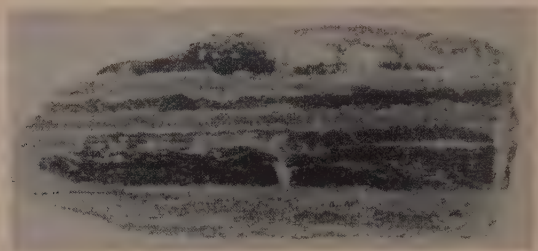


FIG. 1. (Natural size.) Polished surface of gneissoid lapis lazuli from Cascade Canyon, Los Angeles County, California. The dark layers are rich in haüyne.

The only mineral that can be readily determined at sight is pyrite which is sprinkled throughout the specimens in small anhedral crystals and often occurs in bands.

The most abundant mineral of the rock is diopside, which also occurs in anhedral crystals with a high relief.

Muscovite is found in minute tabular crystals.

Some specimens contain abundant calcite, but in others it is entirely absent.

No field study of the Cascade Canyon rock has been made by the writer, but from the specimens available it may be designated as an haüyne-bearing diopside-muscovite gneiss which grades into a gneissoid limestone.

THE BLUE MINERAL

The most interesting mineral of the lapis is of course the blue-colored one, the name of which is in doubt.

In thin sections it occurs in rather small anhedral crystals which average about 0.07 mm. in size. The color in thin sections varies from an intense blue to pale greenish blue and is not always uniform even within the small anhedral crystals. The mineral is usually optically isotropic but the pale greenish blue crystals show weak birefringence (about 0.004). Inclusions are occasionally present. The index of refraction

determined by the immersion method is 1.503 ± 0.003 . (The index of refraction is too high for sodalite.)

The blue mineral is soluble in dilute HCl with gelatinization and the generation of a little H_2S , which may be recognized by placing a small piece of filter paper moistened with lead acetate solution over the end of a test-tube containing the powdered mineral and the acid. After a little time the paper turns black due to the formation of lead sulfide. This is proof that the blue mineral contains sulfide sulfur, since pyrite is not appreciably soluble in dilute HCl.

With HCl the blue mineral, free from calcite, gives abundant calcium sulfate hemihydrate⁶ as well as some microchemical gypsum and also isotropic crystals of NaCl. This is proof that sulfate sulfur as well as calcium and sodium is present. Sulfate sulfur is apparently present in larger amount than sulfide sulfur.

The mineral gelatinizes with dilute HNO_3 and a faint test for chlorine was obtained with AgNO_3 .

The blue mineral is evidently an isomorphous mixture of the h  y  ne molecule and a sodium aluminum sulfide-silicate. The formula of h  y  ne given by Borgstr  m⁷ is equivalent to $3\text{NaAlSiO}_4 \cdot \text{CaSO}_4$. Barth's⁸ formula is: $(\text{Na,Ca})_{4-8}\text{Al}_6\text{Si}_6\text{O}_{24} \cdot (\text{SO}_4)_{1-2}$, but neither Borgstr  m nor Barth take into account the sulfide molecule.

The sulfide-silicate molecule of the blue mineral of lapis lazuli is $\text{Na}_4(\text{Al} \cdot (\text{S}_3\text{Na}) \cdot \text{Al}_2(\text{SiO}_4)_3$ (abbreviated $\text{U}(\text{S}_3)$), according to Br  gger and B  ckstr  m.⁹ Chemical analyses of the blue mineral of lapis lazuli in general prove that the h  y  ne molecule predominates. Br  gger and B  ckstr  m introduced the name lazurite (lasurite) and used it for specimens in which the molecule $\text{U}(\text{S}_3)$ constitutes from one-fifth to one-tenth of the whole. They recognize two kinds of lapis lazuli (lasursteine): h  y  ne lapis lazuli and lazurite lapis lazuli. There is a tendency in the literature to use h  y  ne for the mineral that occurs in lavas and lazurite for the blue mineral of lapis lazuli. A mineral, however, should be defined by its intrinsic characters and not by its mode of occurrence.

It seems clear that the blue mineral of lapis lazuli is simply a sulfide-bearing h  y  ne. Since the sulfide molecule never predominates in any natural minerals, so far as known, and since the name lazurite is easily confused with the name lazulite, why not abandon lazurite as a mineral name? Instead it may be used as the name of the sulfide molecule. To this Strunz¹⁰ assigns the formula: $[(\text{SiAlO}_4)_6 | \text{S}_2] \text{Na}_8$.

⁶ See Staples, L. W., *Am. Mineral.*, vol. 21, p. 625, 1936.

⁷ *Zeits. Kryst.*, vol. 74, p. 119, 1930.

⁸ *Am. Mineral.*, vol. 17, pp. 466-471, 1932; *Zeits. Kryst.*, (A), vol. 83, pp. 405-414, 1932.

⁹ *Zeits. Kryst.*, vol. 18, p. 238, 1890.

¹⁰ *Zeits. Kryst.*, (A), vol. 98, p. 66, 1937.

ACKNOWLEDGMENTS

I am indebted to Mr. R. M. Wilke, Mr. F. J. Sperisen, and Mr. L. J. Simon for specimens of the Cascade Canyon lapis lazuli.

NOTES AND NEWS

A METHOD FOR PHOTOGRAPHING PETROGRAPHIC
THIN SECTIONS AT LOW MAGNIFICATIONS

WELTON J. CROOK, *Professor of Metallurgy,*
Stanford University, California.

In cases where it is desired to record the more gross characteristics displayed in petrographic thin sections, it becomes necessary to produce photographs at comparatively low magnifications, say from $5\times$ to $10\times$. With the photomicrographic equipment ordinarily available, such operations often present considerable difficulties, particularly when a large field is desired.

It is suggested that the problem may be readily solved by the following methods:

The thin section is placed in a Leica enlarger (or similar apparatus used for enlarging Contax and Leica 35 mm. films) and the focussed projected image of the section adjusted to the magnification desired. Instead of printing the image on bromide paper which would result in a reversed picture, it is necessary to substitute a photographic plate or film, and in this way obtain a negative which may be used later to produce contact prints.

Experience has shown that process panchromatic emulsions are suitable for this purpose, especially where the thin section contains colored constituent minerals. Using a Leica enlarger with a 50-mm. lens, stopped to $f:22$ and a projection enlargement of $10\times$, exposure times will range from, say 20 seconds to 60 seconds, depending upon the thickness and color of the thin section, using Eastman Process Panchromatic cut film.

D-11 developer will give excellent contrast but if softer results are desired, D-72, diluted with two parts of water, may be substituted.

An alternate procedure may be adopted which, although more economical in negative materials, does not give as sharp and clear prints as the preceding method. In the alternate method a contact negative is produced by printing the slide directly onto a small strip of Process film. After processing, this strip is then placed in the enlarger and used as a negative.

From an optical point of view, it may be objected that even the first method proposed will not give the same resolution, for a given magnification, as would be obtained if the slide were photographed in the usual

way with a very low power microscope objective. However, such objections are not altogether valid. Without reviewing the whole of the optical principles involved, it may be pointed out that the very low power objectives which must be used in the ordinary photomicrographic procedure are really short-focus photographic lenses which cover a relatively small field, and which do not usually possess a high degree of chromatic correction. In the case of the Leica or similar type of enlarger, the lenses made use of are the same as those used in the Leica and Contax "miniature" cameras. These lenses are of very high grade and are fully color corrected.

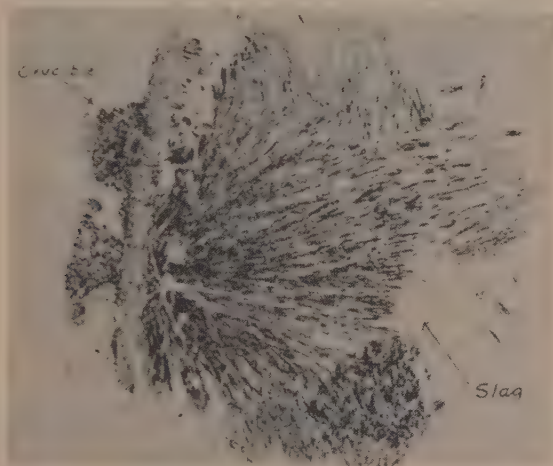


FIG. 1. Slag No. 60. 5 \times . Thin section of crucible and slag.

The writer is particularly interested in the mineralogy of metallurgical slags. The illustrations submitted are photographs, at low magnification, of thin sections of material of this kind.

Figure No. 1, at 5 \times , shows a thin section of slag No. 60. A section of the wall of the magnesite crucible, in which the melt was made, is shown as well as the radiating crystals of the slag itself. The "minerals" present are monobasic ferrite, diopside, and ackermanite.

Figure No. 2, at 5 \times , shows a thin section of slag No. 51. The walls of the magnesia crucible are clearly shown to be unattacked by the molten slag. The "minerals" present in this slag are diopside, monobasic ferrite, ($\text{CaO} \cdot \text{Fe}_2\text{O}_3$) ackermanite, and monticellite.

Although the photographic methods described have been applied by the writer principally to artificial mineral sections, the same procedure may be used for petrographic slides.

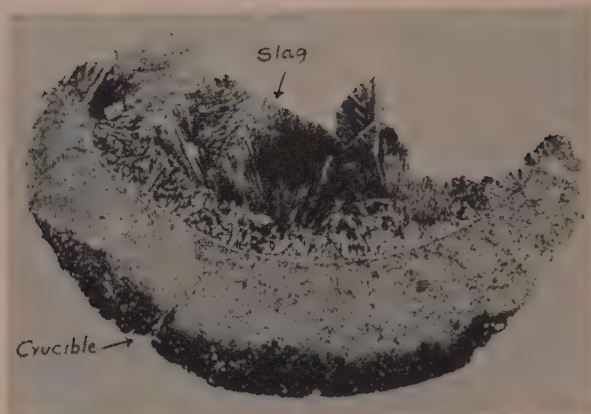


FIG. 2. Slag No. 51. 5 \times . Thin section of crucible and slag.



FIG. 3. Slag No. 101. 5 \times . Thin section. Fayalite-tridymite eutectic with excess fayalite and a small quantity of magnetite.

NOTE ON THE STRUCTURAL RELATIONSHIPS OF
KAOLINITES AND ANAUXITES

F. MACHATSCHKI, *Mineralogical-petrographic Institute of the
University of Tübingen, Germany.*

In his very interesting paper on the densities and structural relationships of kaolinites and anauxites, Gruner¹ mentions that in my review² of his earlier work on the crystal structure of kaolinite,³ I expressed doubt concerning one of his conclusions, namely, that in the mineral anauxite, which is richer in SiO_2 and poorer in H_2O than kaolinite, the Al (with octahedral 8-coordination) might be partly replaced by Si. In my review³ I mentioned another possibility, as follows: "Das Al(O, OH)-Oktaedernetz enthält ja auch Positionen mit tetraedroicher Anionenenumgebung, in welche die überschüssigen Si-Atome ebenfalls eintreten könnten."

In his recent paper, Gruner¹ calls his original proposal of placing Si ions in the positions of Al ions too drastic, and he gives to the Si ions which replace Al ions in the octahedral network 4-coordinated positions. This requires some distortion of the anion packing. Gruner evidently concluded that I proposed to bring an SiO_4 -group into the hexagonal ring shown in Fig. 2 of his paper, for he states: "For example, it would be possible, though unlikely, to place an SiO_4 -group in the hexagonal ring shown in Fig. 2, a position to which Machatschki probably referred. The density would be materially increased, however, and a very large part of the H_2O would be lost, obviously a condition not substantiated by the facts." There is evidently a misunderstanding, for I myself do not understand how an SiO_4 -group could be brought into this position. Therefore, I take this opportunity to give a further short outline of my suggestion.

The so-called Al(O, OH)-octahedral network of the crystal lattice of kaolinite consists of two layers of close-packed anions. This double layer contains positions with octahedral anion coordination $\text{P}^{[6]}$ as well as positions with tetrahedral anion coordination $\text{P}^{[4]}$. In kaolinite, two-thirds of the $\text{P}^{[6]}$ positions are occupied by Al ions, and the $\text{P}^{[4]}$ positions are empty. My suggestion is simply the following: in the kaolinites with an excess of SiO_2 (including the anauxites) the $\text{P}^{[6]}$ and the $\text{P}^{[4]}$ positions are statistically and partially occupied by Al and Si ions respectively. This occurs in such a manner, that contrary to the ideal kaolinite lattice, some Al ions are removed and about the same number of $\text{P}^{[4]}$ -positions

¹ *Am. Mineral.*, vol. 22, p. 855, 1937.

² *Neues Jahrb.*, Referate I, p. 439, 1933.

³ *Zeits. Krist.*, vol. 83, p. 75, 1932.

are now occupied by Si ions. Even now neighbouring polyhedrons need only share corners and no edges and faces: at the same time the OH ions of the ideal kaolinite lattice must be statistically replaced in the required amount by O ions; probably not singly, but groups of Al ions will be replaced by groups of Si ions in this way. The relative positions of the anions will remain unchanged; the closest packing, therefore, will not be distorted.

As far as I can see, this proposal is not in contrast with the diminished H₂O content of the anauxites; and even the new careful determinations by Dr. Gruner do not give a clear picture of the real density curve. The cation distribution in the "octahedral networks" of the anauxites may not be quite as tight as in the ideal kaolinite. Still some anions may be removed in the sense of the proposal put forward by St. B. Hendricks.⁴

I can not give, of course, any proof of the suggestion outlined above, at this time; but I prefer this explanation, because Dr. Gruner's proposal involves a rather serious distortion of the anion packing.

⁴ *Zeits Krist.*, vol. 95, p. 247, 1936.

SOME METAMORPHIC TERMINOLOGY

HOMER D. ERWIN, *Los Angeles, California.*

Although the science of petrography already possesses a rich and varied nomenclature, it is the purpose of the following brief notice to present some additional petrographic terms.

TABLE 1

Distinct mineral body	Texture or structure	Rock type(s)
<i>PHENOCLAST(S)</i> Porphyroclast(s) Blasto-phenocryst(s) Augen, "eyes"	PORPHYROCLASTIC Blasto-porphyrific Pseudo-porphyrific	PORPHYROCLAST(S) Cataclastite Porphyroid
<i>PHENOBLAST(S)</i> Porphyroblast(s)	PORPHYROBLASTIC Pseudo-porphyrific	PORPHYROBLAST(S) Garnet mica schist
PHENOCRYST(S)	PORPHYRITIC	PORPHYRY(S)

Table 1 shows two proposed metamorphic terms to be known as *phenoclast* and *phenoblast* with accompanying textural or structural and rock type terms in contrast to the term phenocryst and corresponding terms applied to porphyritic igneous rocks. Besides being self-explanatory and hence comparatively simple, these two terms make for complete uniformity and consistency in the terminology as shown in the table. Likewise, they are etymologically sound.

The term phenoclast (meaning a distinct fragment in Greek) would apply to the larger of surviving fragments of original minerals in cataclastic rocks which simulate a porphyritic appearance. As such, they may be remnant phenocrysts or the larger of surviving mineral fragments, spared by intense shearing of non-porphyrific rocks such as crystal-, crystal-vitric-, and vitric-crystal-tuffs.

The term phenoblast (meaning a distinct sprout in Greek) would apply to idioblastic crystals which occur in thermodynamically metamorphosed rocks having a pseudo-porphyrific appearance.

Table 2 shows several proposed petrographic terms for metamorphic rock structures and their relation to some existing terms. These terms are etymologically sound and apply specifically to rock structures where crushing, micro-brecciation and *clastic flow* has been the chief mode of adjustment of the mineral constituents. This process is in direct contrast to structures in metamorphic rocks resulting from mineral adjustments by plastic flow.

The term *schistoclastic* (meaning divided by breaking, in Greek) is proposed for the structure of pseudo-schistose rocks resulting from cataclasis. It should fulfill a need for such a term.¹

¹ Grubenmann-Niggli, *Gesteinsmetamorphose*, I, p. 451, 1924.

The term *granoclastic* (meaning granular by breaking, in Greek) is proposed for the structure of granulose rocks resulting from cataclasis.

TABLE 2

Structure	Grade of metamorphism	Name according to metamorphic zone
PORPHYROCLASTIC	CATACLASTIC METAMORPHISM	
	(Cataclasis)	
SCHISTOCLASTIC Pseudo-schistose	↓	EPISCHIST(S) Mylonite-Schist(s)
GRANOCLASTIC Granulose		
GNEISSOCLASTIC Pseudo-gneissose	↓	EPIGNEISS(ES) Mylonite-Gneiss(es)
SCHISTOSE	DYNOTHERMAL METAMORPHISM	
GNEISSOSE	↓	
	PLUTONIC METAMORPHISM	KATASCHIST(S) KATAGNEISS(ES)

The term *gneissoclastic* is not precise as to word origin from the Greek as the term gneiss is of Slavonic origin meaning "rotted" or "decomposed." However, on a basis of analogy to the foregoing terms, it should be worthy of recognition. This term would apply to the structure of pseudo-gneissose rocks resulting from cataclasis and for which a term has been needed.²

The terms *epischist* and *epigneiss* would designate schistoclastic and gneissoclastic rocks developed in the epizone of metamorphism as compared to ordinary schists and gneisses developed in the katazone of metamorphism.

² *Op. cit.*, p. 454.

Dr. Raymond J. Leonard, Dean of the Graduate College and Professor of Geology at the University of Arizona, died November 20, 1937, at Tucson, Arizona.

Dr. Balthaser Gossner, Professor of Mineralogy and Director of the Mineralogical Institute and of the Mineralogical Collections at the University of Munich, died on Nov. 7, 1937. He was born Jan. 3, 1877.

Dr. Friedrich Klockmann, Professor of Mineralogy, Petrography and Economic Geology at the "Technischen Hochschule" in Aachen, died on Nov. 17, 1937, in his eightieth year.

Professor Paul F. Kerr of the Department of Mineralogy, Columbia University, has been selected as the Orton Memorial Fellow Lecturer. His subject, "A Decade of Research on the Nature of Clay," will be given at the fortieth annual meeting of the American Ceramic Society to be held at New Orleans, Louisiana, March 27-April 2, 1938.

PROCEEDINGS OF SOCIETIES
MINERALOGICAL SOCIETY OF GREAT BRITAIN
AND IRELAND

Anniversary Meeting, November 4

The following were exhibited: Beryl from the Beam Mine, St. Austell, Cornwall; by Dr. A. F. Hallimond: specimens of russellite and other minerals from Castle-an-Dinas, Cornwall; by Mr. Arthur Russell: an electric counter for automatically counting grains while their diameters are being measured by a recording micrometer; by Dr. A. J. Dollar: meteorites from California, Texas and Kansas: collected during the last five years by Mr. H. H. Nininger (exhibited by Mr. F. W. Cassirer).

The following papers were read:

- (1) **Scawtite pseudomorphs after spurrite at Scawt Hill, Co. Antrim, Northern Ireland.** By PROF. C. M. TILLEY.

Scawtite, previously described from the endogenous contact-zone of the Scawt Hill dolerite, is now recorded in a different paragenesis—associated with spurrite-marbles and spurrite-larnite-rocks from the same locality.

- (2) **The occurrence of acmite in the riebeckite-microgranite of Mynydd Mawr, Carnarvonshire.** By DR. S. R. NOCKOLD.

The previously unidentified mineral, occurring as colourless or pale yellow acicular crystals, in the riebeckite-microgranite of Mynydd Mawr, is now shown to be acmite. As it is quite plentiful in the thin sections examined, it is suggested that riebeckite-acmite-microgranite would be a more correct term for the rock.

- (3) **The composition and paragenesis of the hornblendes of the Glen Tilt Complex, Perthshire.** By DR. W. A. DEER.

Hornblendes are the dominant ferromagnesian minerals in the intermediate and basic rocks of the Glen Tilt Complex. Nine hornblendes from the diorites, appinites, hornblendite and hornblende-schist xenoliths, and the injected hornblende-schist of the country rock have been examined chemically and it is considered that the results may give some indication of the history and mode of formation of the rocks in which the hornblendes occur and will also indicate the possible range of composition of common amphiboles within the diorites and related rocks of a single complex. Large differences in composition are found between the early and the later hornblendes.

- (4) **Russellite, a new British mineral.** By MR. F. A. BANNISTER and DR. M. H. HEY.

The new mineral, which occurs sparingly at the Castle-an-Dinas Wolfram mine, St. Columb Major, Cornwall, is a mixed crystal of bismuth and tungstic oxides approximating to the composition $\text{Bi}_2\text{O}_3 \cdot \text{WO}_3$. The x -ray data indicate that it is not a bismuth-tungstate as at first thought. The minute crystals are tetragonal, a 5.42, c 11.3 Å., space group D_{2d}^{12} , and the repeat is $(\text{Bi}_2, \text{W})_4\text{O}_{12}$. A description of the occurrence and accompanying minerals by the discoverer, Mr. Arthur Russell, is appended.

- (5) **A re-examination of cliftonite.** By DR. M. H. HEY.

At the suggestion of Dr. H. Berman, an x -ray examination has been made of cliftonite. (L. Fletcher, 1887). It proves to consist of graphite micro-crystals arranged with their c -axes parallel to the three tetrad axes of the cubes. This suggests that it is probable that the crystals are pseudomorphs, but the original mineral has not been identified.

NEWARK MINERALOGICAL SOCIETY

The 170th meeting of the Society was held in the Newark Turnverein Building on Sunday, October 3, 1937. This was the first meeting since the summer adjournment in May 1937. The program consisted of a talk by Mr. Ernest A. Maynard on *The Minerals of Florida*.

The 171st meeting of the Society was held on Sunday afternoon, November 7, 1937.

The 22nd Annual Meeting followed a short business session when the annual report of the Secretary, Herbert L. Thowless, was presented. The Society unanimously re-elected its officers, namely:

Vincent Giordano, President.

John Reiner, Vice-president.

Wm. H. Broadwell, Treasurer.

Herbert L. Thowless, Secretary.

At the conclusion of the annual meeting the remainder of the afternoon was devoted to a symposium on *Lead Minerals*. Louis Reamer opened the program with a general talk on the subject and was followed by Richard P. Milburn on the commercial uses of lead. Both talks were illustrated with specimens.

On Sunday, November 21 a number of the members enjoyed a field trip to the trap rock quarry at Summit, N. J. Although the weather was cold and there had been a snow-fall covering the ground this did not interfere with the search for minerals. Considerable calcite, heulandite, prehnite and other minerals were obtained.

The 172nd meeting was held on December 5, 1937 and the business session was followed by the reading of a paper on *Radium Minerals* by Paul Walther. Short talks were given by other members on the same subject and a large number of radio active minerals were on exhibit.

HERBERT L. THOWLESS, *Secretary*